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"A CONTRIBUTION TO THE MORPHOLOGY AND MECHANISM OF THE HIP JOINT".

PREFACE.

There is submitted in this thesis a theory of the mechanism of the hip joint opposed in its most fundamental conception to the presently accepted 'ball and socket' view. Yet the basis is strictly morphological: the results are founded on the systematic examination of over one hundred complete joints supplemented by more extended observation of those details especially controversial, and inclusive of the detailed study, and in many cases of section, of a large number of macerated bones. Throughout the major part of the work the usual lines of anatomical research have been followed,- the adult formation has been compared to and contrasted with the embryonic, the comparative, and the pathological homologue: but we believe it is with profit that a reversion has been made to the physical aspect of organic structure.

Of so vast a literature as exists on the hip joint it is hardly possible, nor is there need, to have indicated the whole. The most permanent contributions have been freely consulted, and personal verification made of the facts accepted.

Certain of the sections into which subdivision has been made may seem to have obtained an undue emphasis, but it is hoped that it is possible to recognise throughout the ultimate aim,- the establishment of the mechanism of the joint.

INTRODUCTION.

The present tendency in the explanation of the mechanism of a joint is to refer to all its movements in terms of artificial combinations. This error, as we believe, has arisen through the non-recognition of those principles of construction which are peculiar to organic joints. Reference to the various theories of the mechanism of the hip joint, or rather to those main views of which there are many minor modifications, may be made subservient to the consideration of the fundamental differences between a mechanical combination and an organised articulation. The oldest theory and that which is still most widely held was advanced by the brothers WEBER. Herein it is held that the hip joint is a ball and socket joint: that the acetabulum is the accurate counterpart of the head of the femur: that the two articular surfaces are curved to the same radius and both are perfectly spherical: and that the limits of normal movement are found through the checking action of the joint ligaments and the ligamentous action of the surrounding muscles, these alone being held sufficient for the production of ~~the~~ stability ~~of~~ in complete extension. In this acceptation the essential principles of a mechanical combination are defined: the opposing surfaces are surfaces of revolution and all sections at right angles to their axes are mathematical circular arcs: all movements at the joint are of pure rotation round one of the axes, or of a combination or intermediate of any two, and the curvature of the path described by any point on the limb may be directly associated to the moving surface within the joint: further, the whole action areas of both articular surfaces at any given moment of time in any of the movements conceived are in total contact, coincidence, and congruity, and any further movement in the same plane, positive or negative in kind, would in no degree lessen the amount of surface contact. The effects of the continuation of such totality and constancy of surface action, (the attributes of a mechanical combination,) may at once be recognised as such as would, ~~through~~ by constant pressure ~~determining~~ disintegration of joint surface, as will occur in an organic joint and which may not, like a similar change in an artificial couple, be remedied by outside interference, lead to the speedy injury of joint constitution and the early inefficiency of the performance of joint function. The second theory of the mechanism of the hip joint, therefore, eliminates the totality of action of the articular surfaces at any given moment. According to KONIG the joint surfaces are truly spherical but that of the acetabulum is of a greater radius, so that, theoretically, the two bones are resting together at only one point in any position of the articulation. On comparison with the theory of the WEBERS', that of KONIG is in fundamental agreement regarding the circularity of the articular arcs, requir~~ing~~e a retention of the description of the movements of the joint as those of rotation. In fundamental difference is the localisation of the surface contact, corollary to ~~which~~ this is the underlying principle that all other surface areas are, at that given moment, incongruous or inactive: in all, a due recognition of the principle of the mechanism of an organised articulation,- the necessity of the succession of functional contact and of a period of rest or inactivity, during which there may be a restoration of the deterioration of organised matter incidental to its term of activity. In objection, however, to KONIG'S theory is the minimal nature of the possible congruity in those positions in which stability is characteristic of the joint: for no spherical combination, artificial or otherwise, and in the latter even in the highest activity of ligamentous or muscular support, apart from an impossible internal multiplicity of ligament or an unnatural maintainence of muscular contraction, ~~can~~ retain its stability with a contact confined to one meridian. The succeeding theories, therefore, are found to be essentially similar to one another in their definition of the only further rational modification of the construction of a stable combination, this ~~in that there is held to be~~ a departure of the joint surfaces from the spherical form, thus ensuring not only the required succession of surface contact but also that the areas of congruence are of dimensions sufficient for the functions of the joint: but in the modifications put forward by AEBY and by KRAUSE there is not a definiteness such as might have been expected if founded on the works of MEYER, of MEISSNER, or of LANGER, while GOODSIR'S contribution is lacking in descriptive detail, possibly ~~through~~ not having been completed for publication. As defined by AEBY from the results of measurements, and supported by the facts of comparative anatomy, the head of the femur is not spherical but is 'an oblique pole segment of a rotational ellipsoid'. GOODSIR, on the other hand, does not attempt to define the geometric forms of the head of the femur or of the acetabulum, or those to which they most closely attain, but states that the mechanism of the joint is in the alternate action of two screws, the head of the femur being 'facetted' in two separately acting areas, anterior and posterior in position. These conclusions are fully entered into later, but it is necessary to recognise that dependent only on these or on similar views is there the application of the fundamental principles of organic joint construction to the elaboration of the mechanism of the most highly modified human articulation, the hip joint. In brief enunciation these principles are:- that sections of the articular surfaces at right angles to their axes are not mathematical arcs, so that they are not surfaces of revolution: that the movements within the joint, influenced by the configuration of its surfaces, w~~ill~~ not ~~be~~ movements of simple rotation: that the whole of either articular surface ~~will not~~ ~~be~~ in reciprocal congruence with its complement in any position of the components concerned, but w~~ill be~~ in part in action and in part inactive or at rest.

The high degree of modification of the human hip joint is dependent on its dual function: for not only does it require to serve as the sole means of locomotion in its attribute of almost excessive mobility, but its stability must be of a maximum requisite to form the sole means of transmission of the whole body weight. For both purposes the same morphological details are, in their function, efficient. First, the reciprocal configuration of the separately acting areas of the opposing articular surfaces: second, the guiding and supporting action of the joint ligaments and the accessory capsular structures: third, the initiatory and controlling mechanism of the joint muscles. A series of simple examinations will define the relative activity of these factors as determinant of the movements within the joint. By disarticulation at the sacro-iliac synchondrosis and section at the anterior symphysis an entire limb is isolated from the trunk, and from the pelvic aspect an 'acetabular window' is formed, leaving intact the synovial membrane and the extra-synovial fat. The pelvic element is fixed, and means adopted to record the position of the limb at the limits of the movements of flexion and extension. 1. The synovial membrane is intact:- Commencing from the position of semi-flexion, the 'mid-position', allow the weight of the limb to determine its position in full extension. During the whole movement and with a perceptible increase towards its termination the extra-synovial fat is protruded into the opening made at the acetabular fossa. On reversion to the mid-position a recession of the fat within the cavity occurs. On passing onwards to the position of full flexion and on subsequent reversion, exactly similar movements of protrusion and recession are undergone by the fatty pad. A hand placed on the limb during the whole excursion of the movement from full flexion to full extension detects no break of articular surface contact at the moment when the fat is at rest between the two phases of movement. 2. Remove the synovial membrane and the overlying fat:- The head of the femur is visible in its movements while the limb performs its excursion from the mid-position in both directions. Without entering into detail the movement of the head as a whole may be observed as a progression forwards, upwards, and inwards throughout the positive phases of both motions, and as a recession through an opposite path during the reversion to the mid-position. 3. Remove All the muscular structures round the joint are removed, leaving the capsule entire: destroy the surface cohesion between the articular elements:- In the mid-position the capsule is of a laxity sufficient to allow the head of the femur to be separated from contact with the acetabulum, the apical displacement amounting to 1. to 1.5 cms. On passing towards the position of extension the head is reintroduced within the acetabulum, so that at the conclusion of the movement it has travelled along a path similar to, though more extended than, that indicated above: and there is no increase in the amplitude of this movement of the limb. 4. Completely section the capsule and divide the ligamentum teres, so that there is no organic connection between the femur and the pelvis:- Introduce the head of the femur within the acetabulum as far as is possible in the mid-position, and maintaining its contact with the acetabulum by pressure from without, allow the limb to pass towards the extended position. The head of the femur moves along the previously described path, but at the moment of the continuation of the movement beyond the former limit of extension the articular surfaces will be detected to break contact in what may be termed a 'surface dislocation', and the head of the femur recedes from the acetabulum. The shape of the articular surfaces, therefore, and not the muscular or ligamentous connections, is the ultimate determinant of the movements of the bones relative to one another within the joint.

We propose to approach the study of the mechanism of the hip joint from the three stages of the foregoing experiment: to determine,

1. the action of the joint muscles:
2. the mechanism of the capsule: and,
3. the configuration of the articular surfaces.

In each section we deal first with the morphology of the structures concerned, and subsequently with their 'physical anatomy' and mechanism.

- P A R T O N E. -

"THE MUSCLES OF THE HIP JOINT."

THE MUSCLES OF THE HIP JOINT.

The functions of muscular tissue (1) relative to the mechanism of a joint may thus be summarised:-

1. the displacement in space of one or both of its osseous attachments:
2. the fixation of its attachments in certain of the positions of displacement, either by active contraction and the establishment of balance between its opposing groups, or by a ligamentous action, according to the relation of the position assumed to the possibility of action of the other factors involved in the determination of stability: in the full action of these other factors muscular contraction is unnecessary: and,
3. the retention in contact of the opposing joint surfaces in those positions in which the laxity of the articular capsule might permit of a separation.

We shall treat of the muscles of the hip joint according to these definitions.

1. THE MUSCLES AS EFFECTORS OF MOVEMENT.

The attitude of standing and the motions of walking are those, [illegible] of all ~~of~~ which the body may perform, that have been thought most suitable of explanation on

1. There are, of course, points of morphological importance in connection with the muscles of the hip joint, but as these in the main relate to their possible formation of the capsular ligaments, they are discussed with the morphology of the capsule.

mechanical principles. It is probably on this ground that so divergent are the conclusions arrived at: for the manner of maintainance of the equilibrium on both limbs, or on one, is as variable as the variety of body attitudes assumed, is shared in by the whole body, and is not a peculiar function of the hip joints. The essential functions of the sacral extremities are not such as are concerned in the preservation of balance, but as agents of transmission of the already equipoised body weight: and as means of progression, so that the essential movements of their component articulations are those of the plane of the progressive movement. In biped progression, especially, accessory movements are necessary at the proximal articulation, in that it is necessary ~~will be required~~ that the gravity line of the body should be capable of a range of displacement sufficient to establish its direction, alternately, in that of the axis of the supporting unit: ~~and~~ these displacements of the trunk will be inflections about an antero-posterior axis, and further, to permit of the forward movement of the body, rotations round a vertical axis. These accessory movements are constantly ascribed to the femur as abduction and adduction, and of rotation internally and externally, so that the classification of these as primary movements of the thigh ~~as these in addition to~~ the essential movements of flexion and extension is useful only as descriptive of its possible displacements relative to the trunk: for the actual movement of the limb in the motion of progression will be defined in the plane of progression, though the relative movement, and such as will occur at the joint, may be a combination of the three alternatives. Accepting, however, the traditional description of the movements as those of the limb, and without reference to those occuring at the joint, an analysis of their extent and incidence is required.(1) It is not practicable to determine a position from which movement of the limb in every direction would be of equal amount, so that recourse is made to what is termed the 'normal position' from which the amount of movement in any direction may be measured. In this position the 'mechanical axis' of the femur, that is the line from the centre point of the head to the centre point of the extremity at the knee, is vertical, and if continued downwards passes through the centre point of the ankle joint: as seen from the front the 'anatomical axis' of the shaft forms with the mechanical axis an angle of 5° to 7°, and the plane of the pelvic inlet is inclined to the horizontal at 55°. From this position flexion in a purely vertical direction is possible to 121°, and extension may be carried out through 13°, the total possible excursion in this plane thus being 134°. (BRAUNE gives 135°, WEBER 139°.) The influence of the accessory movements on the range of motion in this plane is such that a combination of any of the alternatives to any extent will diminish the total excursion, apart from an increase of 1.5° when 0° of rotation is combined with 5° of abduction. (MEYER.) From the 'normal position' an excursion of abduction and adduction(2) in a plane

1. The description given is founded on that of FICK.
2. As descriptive of these movements we would prefer the term of 'side elevation' from and towards the trunk, and to refer to the movements of abduction and adduction when the bone as a whole is carried away from or towards the median plane.

at right angles to the former vertical is possible to the extent of 74°, while rotatory movements round the mechanical axis[1] may occur through 49°. On mapping these figures and those obtained in other planes of movement on a graduated sphere, the extent of movement in any given combination may be determined: and an analysis of such demonstrates that the greatest amount of both flexion and extension occurs in a combination of abduction and external rotation: and further, that the direction

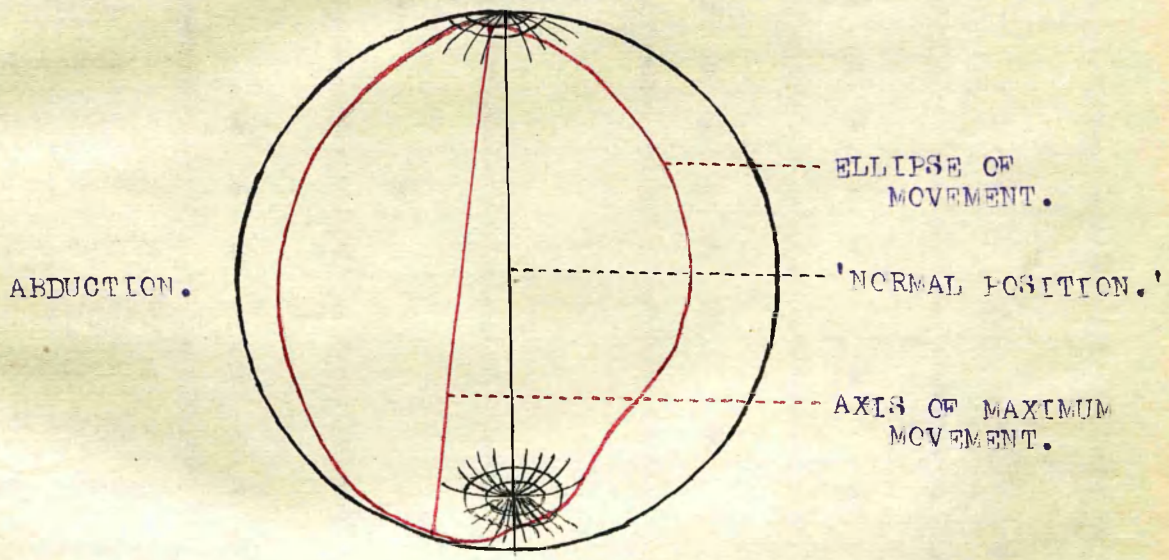


Fig. 1.
The movements of the right hip joint as seen from the front. (after FICK.)

of this movement is not in a plane parallel to the vertical but inclined from it at the completion of extension. (fig.1.)

1. It is of course freely admitted by FICK that rotatory movements of the limb cannot take place at the joint round the axis of the shaft.

An analysis of the action of the muscles productive of the primary movements of the limb also defines the composite nature of the displacement resultant of the contraction of any unit or group. (Table 1.) With action of

TABLE 1.

	Flex.	Ext.	Abduc.	Adduc.	R.Ext.	R.Int.
Glut.max.		+		+	+	
Glut.med.		+	+			+
Glut.min.	+		+			+
Pyriformis.		+	+		+	
Obt.int.		+		+	+	
Gemelli.				+	+	
Quad.fem.	+			+	+	
Adduc.mag.	+	+		+	+	+
Adduc.brev.	+			+	+	
Adduc.long.	+			+		+
Gracilis.	+				+	
Pectineus.	+			+		+
Rect.fem.	+		+		+	
Ilio-psoas.	+					+
Tens.f.fem.	+		+		+	
Semitend.		+		+		+
Semimemb.		+		+		+
Biceps.		+		+	+	
Obt.ext.	+			+	+	
Sartorius.	+		+	+	+	

Compiled from various sources. The popliteus is not reckoned as a femoral muscle.

units we are not at present concerned: but it will be observed from table 1 that the full action of the sum of the units productive of extension is such that its accessory accompaniments will be abduction and external rotation of the limb, or those movements of the trunk which would determine these relative displacements: and the adduction action of the m. glut. max., then in operation, would tend to prevent the body rolling inwards on the limb by the closer approximation of the articular elements at the hip joint. There are other facts regarding the action of these hip joint muscles which might well be discussed, but relative to the mechanism of the joint all conform to one principle: that whatever be their course of contraction, or whatever the combination in which they may contract, there are no changes in the position of the limb, (~~which is~~ the only result of their contraction,) which will produce movements of the joint of which it is not already capable in virtue of the shape of its articular surfaces and the connections of its capsular ligaments. The action of muscles is expressed in movement of the bone, but the relative configuration of the articular elements determines the movements at the joint.

2. THE CHECKING ACTION OF MUSCLES.

In the experiment described in the introduction it was indicated that after removal of the muscles from the joint preparation there was no increase in the amplitude of the movement of extension. In other directions, however, the possible excursion of the limb is augmented: and this is the result of the absence of the checking action of muscles.[(1)]

The incidence of the limitation of limb movement through muscular action may be determined by a comparison of the 'ellipses of movement' of a preparation with the muscles intact and of one in which the ligaments alone are preserved. (FICK.) Such a comparison demonstrates that the muscular checking mechanism affects mainly the excursion of flexion and adduction, the ellipse of movement of the ligamentous preparation exceeding that of the entire limb throughout these areas: in the range of extension and abduction, on the other hand, the ellipses are identical, so that if there be a muscular checking of these motions its action must be coincident with that of the capsule. The outstanding fact of the incidence of the muscular limitation of movement being, that the positions in which the muscles become active are those that are unusual, it is possible to indicate in some measure, the nature of muscular action in its function as a checking mechanism. Between the separate articulations of a limb there is such an interdependence of movement by reason of ~~through~~ the associated action of muscles pertaining to more than one of the joints, that normal movements at one joint are, normally, continuously associated with or productive of definite and peculiar movements of the others: and in the supporting limbs

1. The fixation of the limb by active muscular contraction occurs only in unnatural positions, in which the factors normally productive of stability are necessarily inactive, and for limited periods of time. This aspect of the checking action of muscles, therefore, does not concern the mechanism of the joint.

of man, as in those of other animals, even though the movements of individual segments of the limb be in opposite directions, the ultimate aim of the combination is the establishment of the limb in a position of stability, and its retention in that position in the entire absence of active muscular contraction. The normal checking mechanism of muscles is not, then, in their active contraction. At the hip joint the limit of flexion is reached in the action of the hamstring group: and the position of commencement of their action on the excursion of movement depends on the state of the knee joint. If that joint if flexed fuller flexion of the hip may be obtained than if the knee is extended. The limit of motion is the result of the shortness of muscle, in function an approach to that of ligamentous structure: (CLELAND:) and this shortness of muscle is only apparent in positions which are unusually assumed. It is found, therefore, that there are no great individual differences in the amount of movement allowed at the hip joint: and if an excess of movement is possible in acrobats, dancers, and similar people, it is confined to those directions in which muscles normally act as the checking mechanism,(1) and is the result of 'training' at those early periods at which muscles exercise no limiting action. So far as normal motions are concerned muscles have no part in the limitation of the movement.

1. KEITH brought before the Anatomical Society in Nov. 1896, (Jour. Anat. & Phys. vol.31.) a Punjabi, who could throw his limbs into abnormal positions owing to a power of hyper-flexion. There was, however, no hyper-extension possible at any joint.

3. THE ACTION OF MUSCLES IN RETAINING THE JOINT SURFACES IN CONTACT.

A mechanical combination is always so constructed in the precise reciprocal configuration of its surfaces that a separation of its elements in their action is impossible: either in virtue of the grasp exercised by the longer arc of one of the components, or through the constant action of weight superimposed from the exterior. Organic joint surfaces, at least those of the diarthroses, on the other hand, will not of themselves remain coincident, but are retained in contact through the action of those structures which form their superficial investment, the peri-articular capsule and the joint muscles.(1) The former structure, however, being incapable of alteration in its length, will, during the movements of its attachments, be in states of varying tension: in certain positions, those of approximation of its attachments, the capsule will be slack, so that, in respect to it, dislocation of the joint surfaces is possible. The capsule, then, will only be the means of retaining the joint elements in contact in those positions in which its fibres are fully stretched, and in the hip joint this is the position of extension: in all other positions the surfaces are held together by the action of the muscles, in the absence of which separation may be effected, in the hip joint at semi-flexion to an extent of 1. to 1.5 cms.

The muscles so act on the joint, first in their active contraction, (fig.2:) and it has been determined by FISCHER that the 'joint component' (A) of the resultant of

1. The skin and superficial fascial bands are omitted.

contraction (F) is, in most cases, actually of greater quantity than the 'displacement component' (B). Secondly, as a result of

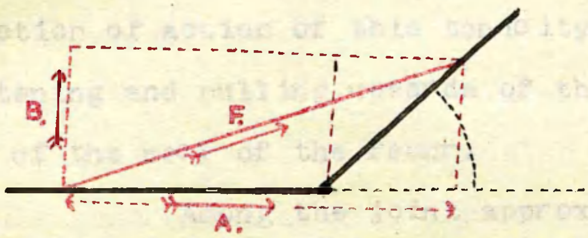


Fig. 2.
The 'joint action' (A) of a contracting muscle (F).

their stretching when functionating as an 'opposing group', muscles attain their ligamentous action, and act as joint approximation forces: and this mode of action becomes of first importance when the joint components are placed at acute angles to one another, (fig.3,) for then the 'joint component' (A) of

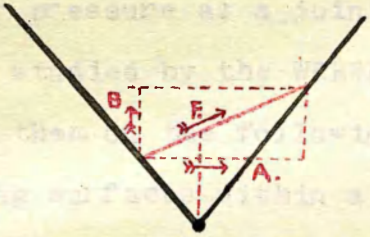


Fig. 3.
The 'ante-joint action' (A) of a contracting muscle, (F) with an acute angle between the joint elements.

the acting muscle (F) is acting, not so as to bring the joint surfaces together, but really so as to force them apart. Again, even if none of the muscles of a joint are in active contraction but are 'at rest', they are, in virtue of their tonicity as evidence of the activity of the nervous system, still powerful factors in holding in contact the joint surfaces. The effects and direction of action of this tonicity are demonstrated in the shortening and pulling upwards of the limb which occur in fracture of the neck of the femur.

Among the joint approximation forces it is necessary to mention those of 'molecular cohesion' and 'air pressure': and more especially as both have a bearing on joint function. For the action of the former force it is essential that the opposing surfaces should be absolutely reciprocal, perfectly smooth, and in contact through a surface fluid medium. The primary condition is unfulfilled in organic joints, since, (and we quote FICK, Teil 2.S.42,) "the joint surfaces are not fully congruent with one another". This force then, plays but a small part in retaining joint contact. The mechanism of air pressure as a joint approximation force has been very fully studied by the WEBERS and their pupils, and is explained by them on the following principles. The separation of two unyielding surfaces within a closed space will give rise to a vacuum interval if the containing walls are solid: and on removal of the force of separation this vacuum will act so as to re-establish the surface contact. If the containing walls are mobile or yielding, however, they will collapse as far as is possible and so long as they are under pressure above that of the vacuum, until they obliterate that interval. In the hip joint the head of the femur is so grasped by the cotyloid ligament that the acetabular cavity becomes the closed space in which the movements happen: and the 'capsule space', lateral to the ligament, is not in communication with that cavity nor do movements of unyielding elements relative to one another occur within it.(1) The wall of the acetabular cavity is morphologically of two parts, a solid unyielding peripheral or articular part and a central part formed of a mobile mass of fat, the acetabular extra-synovial pad: and this latter part of the acetabular wall may react directly to the external atmospheric pressure in that it communicates with the extra-acetabular structures through the acetabular gap. The separation of the head of the femur from the acetabulum, therefore, would be attended by two results: first it would produce a 'collapse' of the acetabular fat to occupy an apical loss of contact, and second, the solid elements could only separate from one another,- beyond an interval which may be occupied by synovial fluid, against the action of the vacuum which would be created.

This force of 'air pressure' then, plays some considerable part in the joint mechanism, but it is necessary to determine its quantitative and qualitative relation to the 'muscular pull' in holding the joint surfaces together. On this subject reference may be made to the detailed researches of BRAUNE, FISCHER, and A.E.FICK, all of whom have arrived at the conclusion, in complement rather than in opposition to that of the WEBER'S, that "it is through the muscle pull that the

1. In an intracapsular fracture of the neck such movements would occur.

joint surfaces are not only brought into intimate contact, and retained there, but are tightly pressed against one another: that the air pressure acts in a similar manner though in varying degrees: and that both forces are necessary, for neither the one nor the other can act alone in retaining the surfaces in contact in all the different positions of the limb."

P A R T T W O.

"THE CAPSULE OF THE HIP JOINT."

A. THE STRUCTURE OF THE CAPSULE.

1. GENERAL ANATOMY.

The articular capsule of the hip joint is a fibrous stratum of very unequal thickness investing the joint cavity, and lined with synovial membrane. It is divisible into two parts, peripheral and intra-articular. In shape it is a truncated cone, the base being attached more or less round the acetabular margin and the apical part on the neck and head of the femur. It is unlikely that in sole virtue of its cone shape the capsule exercises any retentive action on the head of the femur.

With the exception of the position of the acetabular notch the basal attachment of the peripheral capsule is to the bony acetabular rim, and leaves, especially posteriorly, the outer surface of the cotyloid ligament free. At the acetabular notch the capsule is fused with the transverse ligament and the outer surface of the cotyloid ligament, but the sharp peripheral margin of the latter remains free. As there is no bony attachment of the capsule medial to the transverse ligament, a gap is left between that ligament and the bone: bloodvessels, therefore, do not perforate the capsule in passing into the acetabular cavity underneath the ligament, and expulsion of the extra-synovial acetabular fat, occuring at the completion of extension of the limb, is permissible through the gap. It is to be noted that this gap is not a capsular deficiency, but is between acetabular elements, and

and that the intra-articular portion of the capsule completes the investment of the joint.(fig.4.) On the femoral neck the anterior capsular attachment is to the intertrochanteric line,

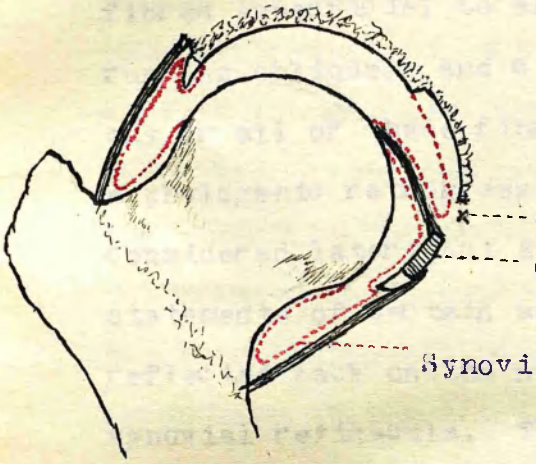


Fig. 4.
Vertical section of the hip joint through the middle of the ligamentum teres. (diagrammatic.)

and traced in a medial direction passes posteriorly above the lesser trochanter at the 'pre-trochanteric fossa'.(POIRIER.) The line of the posterior capsular attachment is about the same distance from the articular margin of the head as it is in front, so that it lies .8 to 1. cm. above the intertrochanteric ridge.(1) Over the superior border of the neck the attachment is medial to the trochanteric fossa. The posterior femoral insertion of the capsule is everywhere weak, and apart from a few longitudinally running bundles is accomplished through arched, concentric, distally concave fibres. In the concavities

1. SAPPEY seems to have originated the description that the capsule was attached posteriorly nearer to the margin of the head than it is anteriorly.

of the most inferior bundles there is only a layer of synovial membrane to represent the capsular wall. Anteriorly, superiorly, and inferiorly the capsule consists of longitudinal fibres superficial to and inseparably fused with deeper layers running obliquely and circularly. The question as to whether any or all of these fibres may be derived directly or through a phylogenic retrogression from the surrounding muscles is considered later: but it is necessary to examine here the statements of certain authors, (FRAZER,) that the capsule is reflected back on the neck and is thus causative of the synovial retinacula. The most satisfactory method which could be determined on, was to split the capsule into layers and to follow each layer to its ultimate osseous attachment. By this means the conclusion was arrived at, that the capsule is not reflected back on the neck, neither in the foetus nor at any subsequent period: that each fibre, which had a femoral insertion at all, was fixed in the neighbourhood of the inter-trochanteric line: but that weak bundles, indefinite but derived from the capsule, passed with the vessels along the neck towards the margin of the head, reaching the vessels at their perforation of the capsule and terminating by blending with their superficial walls and with the superficial structures of the neck round the margins of the vascular foramina.

Those fibres of the capsule which are longitudinal run in a straight course only in a semi-flexed position of the limb, so that with a change of position in either direction the capsule is twisted on itself in a spiral manner. These fibres are arranged in specialised action groups and as such are described as 'capsular ligaments': and the similarity of the movements at this joint in all peoples, determines the great uniformity of the arrangement of these 'strengthening' or 'action' bands. Between these bands the capsule is very much thinner. These thin parts are situated under the ilio-psoas muscle in front, in the neighbourhood of the acetabular notch below, and posteriorly in the region of the great sciatic notch: and from two points of view emphasis has been laid on their incidence. First with regard to the morphology of the capsular ligaments, it has been pointed out that the weak parts of the capsule correspond to the areas of superimposition of muscles: and second, that at their origin they correspond accurately with the depressions of the acetabular rim indicative of the positions of fusion of its component elements, the thicker ligamentous parts, on the other hand, arising from the intervening elemental protuberances. Both descriptions are considered below.

2. THE CAPSULAR LIGAMENTS.

The capsular ligaments of the hip joint are among the best known structures of human anatomy, so that only a short description of each will be necessary.

A. The ilio-femoral ligament consists of two parts, a superior or lateral band and an inferior or medial, and these are, and should be considered, distinct structural and functional units. The lig. ilio-femorale arises from the anterior inferior iliac spine under the tendon of the m. rectus femoris, and on the acetabular rim posteriorly from this for 2. to 3. cms., so that it is seen from behind. It passes outwards, downwards, and slightly backwards, in the plane of the axis of the neck, and inserts itself on to a small, though usually well defined tubercle, (tub. colli sup,, MACALISTER,) on the upper end of the intertrochanteric line, immediately medial to the insertion of the m. gluteus min. It is the shortest of the capsular ligaments, (6 cms.,) and the strongest of the body. (1. to 1.5 cms. thick.) The lig. ilio-femorale mediale is a less powerful band, and is less closely united with the deeper capsular elements. It arises from the anterior inferior iliac spine anterior to the former band, and passes almost vertically downwards, parallel to the axis of the shaft in the upright position, and is attached below on a small eminence, (tub. colli inf., MACALISTER,) at the medial end of the intertrochanteric line lateral to the small trochanter. It is longer than the lateral ligament, (8 cms.,) but distinctly less thick, (.5 cms.)

B. The ischio-femoral ligament is the next strongest longitudinal band. It arises from the ischial part of the acetabular rim near the groove for the tendon of the m. obtutator int., and almost immediately posterior to the origin of the lateral ilio-femoral band: and passing, in the erect position, almost horizontally outwards, only very slightly upwards, is inserted near the trochanteric fossa close to the commencement of the intertrochanteric line. It thus winds itself round the posterior and upper surfaces of the femoral neck.

The description of WEBER. which has led to the designation of this ligament as 'ischio-capsular', that the band fibres are not inserted into the femur but pass circularly to form part of the zonular band, is certainly not wholly correct. The main mass of the fibres, inclusive of all the superficial strata, does obtain an osseous femoral attachment, but it will not be denied in that a few of its deeper fibres mix with the circular group the band has a weak capsular insertion. Superficially the ligament fuses with a fibrous expansion of the tendons of the pyriformis and obturator internus,(FRAZER,)and gluteus minimus. The ischio femoral ligament is about 7. cms. long, 1.2 cms. broad, and .3 to .4 cms. thick.

C. The pubo-femoral band,(1) the weakest of the longitudinal aggregations, is the most variable in its development. The average measurement at its thickest part is .1 cm., its length 7.5 cms., and breadth 2. to 3. cms. It arises from the acetabular margin of the pubis and the anterior surface of the ilio-pectineal eminence and, in the erect position, passes obliquely laterally and downwards to gain insertion at the inferior medial end of the intertrochanteric line fusing there with the medial ilio-femoral band. It is placed between the m. pectineus and the ilio-psoas tendon, and is in intimate structural relationship with the m. obturator ext. by a bundle of fibres which lose themselves in the capsular wall and which in a medial direction may be traced to a fusion with the external layers of the obturator membrane.

D. The zonular band consists of those fibres

1. The designation of this band as 'pubo-capsular' is incorrect..

of the capsule which, describing a completely circular path and obtaining nowhere an osseous attachment, in themselves form a closed ring. There are on record, however, a number of different descriptions. WEBER describes the band as one which arises from the anterior inferior iliac spine and passing postero-laterally in the capsule wall returns anteriorly to its position of origin: LANGER claims that all transversely running fibres of the capsule are derivatives of the ilio-femoral and pubo-femoral ligaments: HENKE says that at its insertion the ilio-femoral band serves as the sole origin for the circular fibres of the capsule. That these views are incomplete rather than inaccurate was first demonstrated by HENLE and subsequently in greater detail by WELCHER: for each described the zonular ligament as of circularly complete fibres. These circular fibres lie deepest in the capsule so that they are seen from its interior after removal of the synovial membrane, and only appear superficially posteriorly between the ischio-femoral and pubo-femoral bands. They encircle the neck of the femur transverse to its axis throughout the whole of its extent, but are so much gathered together at the antero-lateral part of the neck, that at about 2 to 3 cms. under the anterior inferior iliac spine they form a distinct band .5 to .7 cms. thick: anterior and posterior to this aggregation the fibres are less closely drawn together so that the band is broader and thinner. Superficial to these circular fibres are those which, more oblique in direction, arise from the longitudinal ligaments and mingling with the elements of the zonular band form connections between that and the other capsular elements: and of these connections that with the pubo-femoral is the most intimate. In virtue of its concentration on the lateral part of the neck the diameter of the zonular band is smaller than that of the head of the femur.

E. The ligamentum teres:- The femoral attachment of the ligamentum teres is accomplished through two main roots, and an inconstant accessory bundle between them, to the anterior part of the teres fossa. At the acetabular insertion the essential elements pass to the extremities of the articular sickle, the accessory root to the lig. transversum acetabuli. The anterior root is the shorter and weaker, is usually reddish-coloured, and is completely invested at its pubic insertion by the peripheral capsule. The other part of the ligament, the posterior, ischial, or white root, is longer, thicker, and broader than the anterior root, and though attached primarily to the posterior horn of the articular acetabulum, reaches under the transverse ligament so that it can be recognised in the peripheral capsule. In the interval between these bands and arising from the transverse ligament, and inconstantly and insecurely from the acetabular fossa, is the accessory group of weak fibres. That part of the ligament which serves in the adult to demonstrate its capsular origin in that it leaves the acetabular cavity may be observed in various degrees of development. Most commonly after passing under the transverse ligament the issueing fibres mingle with the neighbouring ligamentous origin of the peripheral capsule: less frequently, though WELCHER describes it constant, the continuation of these fibres on the inner surface of the capsule in the interval between the pubo-femoral and ischio-femoral bands may be traced for 2. to 3. cms.: and this bundle, and not as suggested by KEITH the 'reflected ligament of the femoral neck', represents the original continuity between peripheral and intra-articular capsular elements.

Though cases have been described in which the lig. teres was only partially developed, or again entirely represented by synovial membrane or even in which it was completely absent,(1) normal dimensions for the ligament may be stated. In length it is 2. to 2.5 cms., .5 to .8 cms. broad, and as a flat band, its shape when functionally active, .2 to .4 cms. thick. The strain it is capable of resisting is 60 to 70 kilos.

The position of the ligament is such that while laterally it rests on the head of the femur medially it is in constant relationship with the acetabular pad of fat: so that during the movements of the head of the femur it is never placed between cartilaginous surfaces. This fact has given rise to the view that the Haversian pad and the whole non-articular part of the acetabulum are conditional on the presence of the round ligament: so that if the ligament is absent the pad of fat is wanting and the articular surface is complete. This view is considered later.

3. THE ACCESSORY CAPSULAR STRUCTURES.

Under this heading we include the synovial membrane and the extra-synovial fatty pads, both structures which received more consideration at the hands of the older

1. In none of the descriptions of these occurrances to which we have had access has any heed been taken of the possibility of a previous dislocation of the joint, for the development of which there must be a rupture of the ligament.

anatomists than they do at the present day.

A. The extra-synovial fat:- The term 'synovial pad' is applied to a mass of vascularised fat invested by synovial membrane locally modified for the production of synovia. (HAVERS.) In addition to the glandular function of the covering membrane, which has led to their designation of 'Haversian glands', as a whole these masses act as movable pads which are drawn into and occupy the spaces which would otherwise occur between the articular surfaces of joints during their action. This separation of articular surfaces is peculiar of organic joints, and to fill the potential intervals movable and yielding structures are required: such are found in two modifications. If space alone is to be occupied synovial pads fulfil the requirements, but if resistance to pressure is an additional function fibro-cartilaginous tissue is necessary: and since these structures are necessary in the articular mechanism, they are constant and regular in position in each joint, and associated with each pad is a synovial mechanism for regulation of its movements. In connection with the hip joint there are three synovial pads: two are in relation to the articular margin of the head of the femur, and the third is situated in the acetabular fossa. The femoral pads are placed in the superior and inferior concavities of the articular margin at the medial ends of the retinacula of the neck. Both are so freely movable on the under-lying tissues of the neck that on semi-flexion of the limb, when the peripheral capsule and therefore the retinacula are relaxed, these pads react to the suction action generated within the joint, and move so that the inferior comes to lie on the pubic part of the acetabular margin, and occupies an interval which would otherwise be created between that portion of the acetabular surface and the receeding margin of the head. When the inferior retinacula are stretched, as occors in the tightening of the capsule in extension and hyper-flexion, they pull on the synovial pad and flattening it on the neck of the femur remove it from any possible intervention between the articular surface of the acetabulum and the advancing margin of the head of the femur. These synovial pads, then, are placed so as to equalise the uneven articular margin of the femoral head in its varying position on the uniform margin of the acetabulum, and their synovial mechanisms are the retinacula of WEITBRECHT. The acetabular synovial pad is placed in the acetabular fossa superficial to its thin easily detached periosteum, to which it is movably united by weak ligamentous connections and small vascular channels. The connection is so slight that the whole pad may be lifted off with a scalpel handle. The amount of the mass varies individually, and may here and there seem to be deficient especially in the upper part of the fossa, but normally it is of volume more than sufficient to fill the acetabular fossa, the excess being necessary in its function. The movements of this pad are such that on semi-flexion of the limb it passes into the acetabulum under the action of the suction force of the joint, and abolishes the interval which would otherwise be produced by the apical displacement of the head of the femur: and this movement is visible from the peripheral aspect of the joint as an 'indrawing' of the structures superficial to the acetabular gap. On extension of the limb the excessive portion of the pad is visibly protruded through the acetabular gap, and reaches that position not by an expulsive action of the advancing apical part of the femoral head, but by being actively withdrawn by its peculiar synovial retinacula attached to the superficial part of the ligamentum teres.

We believe, then, that these synovial pads are active accessories of the articular mechanism in their function of occupying intervals which would otherwise occur between the more unyielding articular surfaces: and that their movements are controlled by bands of synovial membrane, the retinacula, which are attached on the one hand to the surrounding capsule and on the other are connected to the fatty masses.

B. The synovial membrane:- The synovial membrane of the hip joint is in extent and attachment in common with that of other diarthroses, but there are the retinacula of WEITBRECHT (or ligaments of STANLEY) to lend it a peculiar interest. These retinacula are readily recognised on the interior of the capsule as flattened bands passing inwards towards the margin of the head of the femur from the attachment of the peripheral capsule. From a rather mixed and often negative literature the following description may be selected as expressive of current opinion regarding their constitution: the retinacula are arranged in three groups, superior, middle and inferior: structurally they are synovial covered capsular reflections: morphologically the inferior set is said to represent the persistent retinaculum of the invaginated ligamentum teres, (KEITH, PARSONS:) functionally they are developed either to prevent intracapsular fracture of the neck, (FAWCETT,) or if that has already occurred as a means of fixation of the fragments, (CUNNINGHAM.) Omitting many very possible criticisms of any or all of these views, we state the conclusions we have arrived at from a study of their ontogeny and comparative anatomy. The retinacula are developed over the blood vessels which perforate the capsular attachment and pass along the neck of the femur to enter the foramina towards the articular margin of the head. From their capsular perforations these vessels derive and carry inwards indefinite fibrous prolongations of the capsular wall, which are covered over by reflections of the synovial membrane. The fibrous prolongations terminate by fusion with the superficial structures of the neck at varying and indefinite distances from their origin, while the synovial membrane passes onwards to the fatty masses at the cartilaginous margin of the head. The retinacula thus constituted may be placed in three groups, and such a division is in definite and direct relationship to the positions of the vascular foramina of the neck. We have determined these facts in the adult human subject, in some of the domestic carnivora,[1] certain of the ungulata,[1] and in one of the lower monkeys. In the early human embryo the lig. teres is completely free at the first appearance of the joint cleft: in the embryo tapir a synovial mesentry binds the ligament

1. In these groups there is neither superior retinaculum nor superior synovial pad owing to the shape of that area of the articular head.

to the capsule wall, while in the adult the ligament is grasped as in the adult human subject, (WELCHER:) in the walrus and sea-cow, where the limb pertains to the reptilian type, the ligament arises within the joint cavity permanently enfolded in a synovial reflection from the capsule wall, (MOSER.) We hold therefore that the inferior femoral retinaculum cannot be the persistent remains of the mesentry of the invaginated lig. teres, but that such should, and possibly does occur, as the retinaculum of the acetabular synovial pad, (also described by WEITBRECHT,) which arises in relation to the extra-acetabular part of the ligamentum teres (WELCHER) and invests the vessels passing through the acetabular gap to the acetabular synovial pad. At their medial extremities the femoral retinacula, as already indicated, form the superficial covering of the femoral synovial pads, and these and that related to the acetabular pad form a mechanism, in virtue of their capsular connections, for the regulation of the movements of those masses. At birth the retinacula are of relatively larger size than in the adult, but rather than describe this as evidence of "a natural means of prevention of separation at the hyalo-chondrosis at a time of life when, in virtue of our want of thought, there is most need for it", (FAWCETT,)[1] we would associate the fact with the relatively larger blood vessels which pass to the head at that period. We put forward, then, these definitions regarding

1. At birth the 'hyalo-chondrosis (i.e. the junction of cartilage and bone) would of course be situated on the shaft of the bone below the level of the trochanters. (v. 'Epiphysis of the head.)

the femoral retinacula: their incidence is coincident with that of the blood vessels of the epiphysis of the head and metaphysis of the neck, as determined by dissection in the recent specimen and by analysis of the vascular foramina in the macerated bone: they are reflections of the synovial membrane over the fibrous sheaths of these vessels, and the sheaths are indefinitely derived from the capsule wall: none of them possesses any peculiar morphological significance, but they are developed where they will be free from direct capsular or inter-articular pressure, and are associated with the blood vessels and synovial pads, permanent purposively and precisely in those situations, and serve as a protection for the former and as an active mechanism in the function of the latter.

4. THE MORPHOLOGY OF THE CAPSULE.

The present descriptions of the morphology of the capsule of the hip joint affirm that it consists of two parts, true capsule and false: the former is described as the derivative of the early mesoblastic joint boundary, while the latter is held to be a secondary accession of extra-capsular tissues, according to one view muscular regressives,(SUTTON,) in the opinion of others inter-muscular fascial condensations. (MACALISTER.) Beyond a statement that the peripheral ligamentous bands are the accessories, we have been unable to discover a description of the exact demarcation between the 'true' and 'false' capsular elements, but even in the absence of this basis both hypotheses of the origin of the false structures are much advanced and found themselves on the fact that where muscles or their tendons are contiguous with the capsule there is no development of the capsule wall in the form of capsular ligaments, so that the capsule in those places remains thin. We do not hesitate to deny the necessity of the separation, nor to affirm that the whole capsule is an ontogenetic entity: and we do so from a study of its comparative anatomy, its human ontogeny, and of the mechanism of the capsular ligaments.

A. The comparative anatomy of the capsule:- The peripheral capsular ligaments are fonnd in the anthropoid apes developed to the same extent as (FICK, PARSONS,) or even more prominently than (KEITH) in man, but in the lower monkeys their definition is not so well marked: the zonular band is not evident as separable fibres in either group.(FICK.) Among the quadrapeds the capsule is not markedly differentiated at any part, but it was thickened dorsally in all of those we have examined, (carnivora, rodentia, ungulata,) owing to a development of the lateral ilio-femoral ligament. The capsule is of a laxity sufficient to allow a separation of the articular surfaces from one another, and as determined by a comparison of opposite joints (in the cat) the capsular limitation of movement is active only in adduction of the lower extremity of the bone in the supporting position of the limb: and this limitation occurs in the tightening of the ilio-femoral ligament and of the ligamentum teres. In other directions the limits of movement are more indefinite, and are accomplished by the action of the surrounding muscles, which, in contrast to the human subject, are disposed in contact with the whole superficies of the capsule. There are no accessories to the capsule from these muscles. The comparative anatomy of the lig. teres, the most persistent of all the capsular ligaments, is known better than that of any other joint ligament. The following are the main facts. The reptilian femur is carried outwards somewhat perpendicular to the long axis of the body, and its movements are backwards and forwards on a vertical axis through the head. The capsule of the joint is thickened laterally and medially and each band consists of two parts. If the femur of this type of joint is forced ventrally the medial band tends to enter the joint cavity thus demonstrating the phylogeny of the lig. teres. In monotremes and in the three- and two-toed sloths the ligament is still extra-articular and part of the peripheral capsule: in marsupials and in certain of the edentata the ligament is within the joint though still attached to the peripheral capsule: in the other species in which it is present the ligament is more isolated from the rest of the capsule, though it may retain a mesentery of the capsular synovial membrane or an extra-acetabular capsular attachment to indicate its capsular origin. The ligament may thus remain permanent at different stages of its phylogenetic intra-articular progression. Regarding the described absence of the ligament in certain animals this appears to be due to an ontogenetic retrogression: for in the embryo hedgehog MOSER noted that the ligament was relatively fully developed, though later it has altogether regressed and is completely absent in the adult. According to FICK the same facts are true in the orang, and MINVART has indicated that remants of the ligament may be present in the adult of that species. In the elephant, and as already indicated in monotremes and sloths, the lig. teres is present as part of the peripheral capsule.

B. The ontogeny of the capsule in the human subject:- In reference to the present descriptions of the morphology of the capsule its ontogeny may be discussed in two phases.

1. The perfection of the capsule as a structure enclosing the articulation, subsequent to its definition at the appearance of the joint cleft.
2. The perfection of the capsule as a structure with definite mechanical function.

1. The definition of the capsule:- With this part of the subject we are at present not more than generally concerned. The capsule of a diarthrosis is defined on the appearance of the joint cleft and represents the persistant peripheral mesenchyme of the originally continuous, but now separated, pre-cartilaginous osseous rudiments. Its attachments therefore are at the commencement definitely extra-articular but are so immediately beyond the articular areas. At the 8th. week the capsule of the hip joint is seen to be formed after such a manner and to consist of two differentiated layers. (fig.5.) Peripherally the capsule proper, is continuous at its origin with the perichondrium of the unchondrified cotyloid and transverse ligaments and at its insertion with the perichondrium at the junction of the head and shaft of the femur. The lig. teres is isolated throughout its course from its continuity with the lower part of the peripheral capsule and its attachment to the perichondrium of the

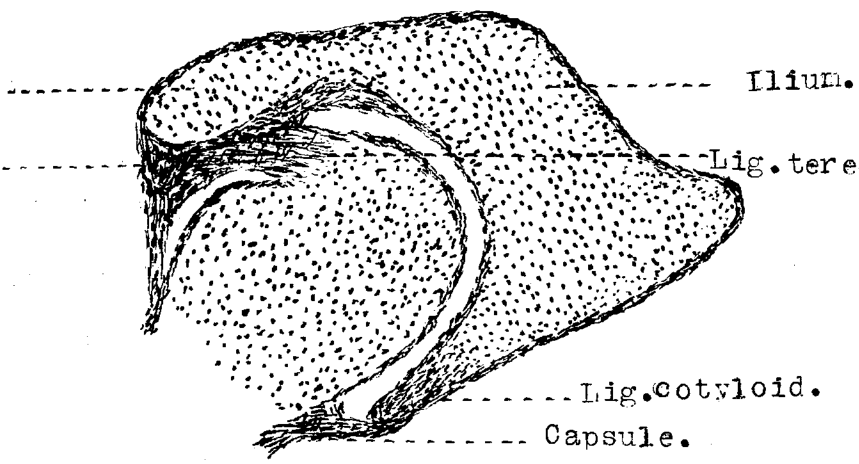


Fig. 5.
Hip joint of a 3 cm. embryo.

elements of the lower part of the acetabulum to its insertion on the perichondrium of the head of the femur in a relatively large transverse cleft. Lining the interior of the peripheral capsule and investing the lig. teres and continuous with the superficial layer of the perichondrium of the pre-cartilaginous bones is that second layer of the capsule, which is ultimately differentiated as the synovial membrane of the joint, though retaining to a later period its primitive perichondrial characters and in the adult occasionally giving rise pathologically to perichondrial derivatives. At the end of the 3rd. month the articular capsule may be said to be morphologically complete and to consist of two parts, the synovial membrane and the extra-synovial fibrous capsule.

2. The perfection of the capsule:- There are two changes of the capsule thus formed which occur in its perfection as a structure

with definite mechanical function, the development of the capsular ligaments and the shifting of the position of its osseous attachments: and both changes are consequent on the definition and elongation of the neck of the femur. The method of study was the dissection of the capsule in foeti from 5 months onwards and after birth in subjects of the ages of 1, 2, 4, 6, 10, and 14 years.[1] In a foetus of 5 months the peripheral capsule is lax enough to allow a considerable separation of the joint surfaces from one another but not sufficient to allow a full dislocation of the femoral head. It may be demonstrated, though more satisfactorily so in a full time foetus, that the capsule is shorter anteriorly than posteriorly probably in association with the flexed position of the limb. The capsule is thicker anteriorly and superiorly but there is no 'band' formation apart from a few fibres which can be determined to run circularly distal to the greatest diameter of the head. In a subject 14 years of age the joint ligaments are formed relatively as in the adult: and between these two specimens, the 5 months foetus and that at 14 years, all the intermediate stages of their development may be observed. The peripheral capsular ligaments are ontogenetically derivatives of the primative fibrous capsule, developed especially anteriorly on the assumption of the erect position so that in that position the head of the femur may be retained within the acetabulum: and these ligaments become more necessary as the neck of the femur elongates, for the joint may

1. A mere statement only is necessary here: a full description will be published later.

no longer be so fully dependent on the normal musculature in the new direction of its axis of movement. There is no gross regression of muscle round the human hip joint but a development of fibrous ligament in the absence of the required ligamentous action of muscle. The lig. teres remains the most developed of the joint ligaments till about 14 years of age, but is relatively larger at birth and for the first 2 or 3 years than it is before or after that period. In regard to the shifting of the attachment of the capsule this occurs at both extremities, so that its basal connection becomes medial to the cotyloid ligament while the femoral insertion is separated from the articular margin of the head by the length of the neck. The latter change is brought about, we believe, rather by the growth at the intra-capsular epiphysis than by a lateral displacement of the capsular insertion.

B. THE MECHANISM OF THE CAPSULE.

1. THE ACTION OF THE CAPSULE AS A WHOLE.

A classification of the forces which check movements at a joint has been made: as in

1. the action of the capsular ligaments:
2. the action of the joint muscles: and
3. the contact of extra-articular bone.

Regarding checking of movement by the contact of the osseous joint elements, the usually cited examples are the limitation of flexion at the elbow and the hip by the coming together of the coronoid process and the humerus in the former case and in the latter the contact of the anterior inferior iliac spine with the neck of the femur. Such a limitation of movement is sudden in onset and absolute in degree, for in its action further movement in the direction in which the contact resulted would be attended by a separation of the joint surfaces from one another, round the area of contact as a fulcrum and in opposition to those forces which retain the surfaces in coincidence. This means of limitation is, however, naturally prevented by other limiting mechanisms, gradual in onset of action and relative, those of the soft parts as a whole or in the action of the muscles or of the joint ligaments. The soft parts as a whole may hinder movement as when the forearm comes in contact with the arm or the thigh with the anterior abdominal wall, but such are indefinite and very relative limitations. The checking mechanism of muscles has already been dealt with, and the conclusion arrived at was that it ~~was~~ is the 'insufficiency of muscle length' which determined a passive or ligamentous limitation of movement in positions which ~~were~~ are extreme or unusual: for example, extreme flexion at the hip joint ~~brought~~ brings into action the hamstring muscles of the thigh and these through their shortness ~~brought~~ brings the movement to a close. The movement of extension, on the other hand, ~~was~~ is not influenced in its extent by muscular action nor is there any extra-articular osseous contact, but the assumption and the maintainence of the position of stability is the result of the action of the articular capsule and its ligaments.

The simplest form of capsular ligament is that which forms the lateral band of a 'hinge joint'. If the movement at such a joint ~~was~~ were such that the path described by a point on the moving surface was the arc of a circle round the axis of the stationary element, as has been described, then the

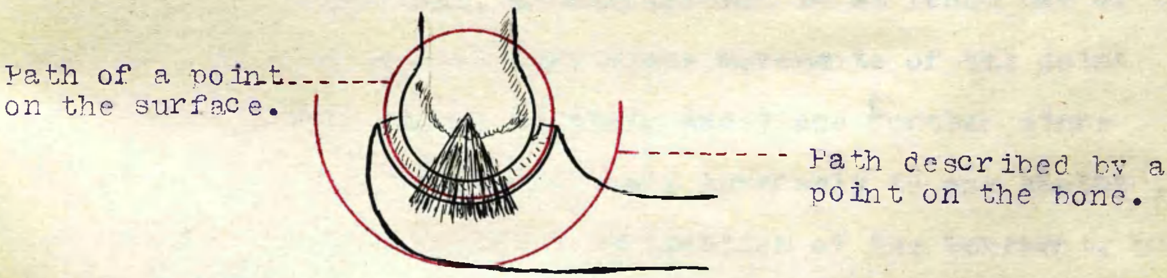


Fig. 6.
A mechanical 'hinge joint': the paths of points on the moving surface and on the bone are concentric circles.

lateral ligament would be continuously (~~never more nor less~~) in action; ~~and~~ it would functionate as a rigid mechanism for retaining the articular surfaces together and in no degree influence the extent of movement in any direction not at right angles to its axis. (fig. 6.) But such is not what occurs: for the action of the ligament may be determined to be at the mid position of the joint and [illegible] in the alternate tightening of the two parts of which it is usually composed. ~~so that~~ Each [illegible] is associated in its action with the commencement of the coincidence of defined and oppositely directed parts of the opposed articular surfaces, and the whole ligament is tightened only at the moment of transition between the two articular couples. Movement in either direction from the position in which the ligament has been tightened produces, in virtue of the shape of the articular surfaces, a slackening of the ligament and the coming into action of complemental areas of the articular surfaces. The lateral ligament of a hinge joint, then, is in action at the mid position of the articulation and retains the coincidence and initiates the congruence of the articular elements. In a 'ball and socket' joint, on the other hand, a modification in at least one of the lateral ligaments is necessary since movements of the joint may occur at right angles to their axes; ~~and~~ further, since the articular surfaces may not vary inversely to one another, and so of themselves induce a termination of the movement, but each must remain an accurate converse of its complement, ~~for~~ in order to establish ~~the production of~~ a position of stability, the modification of the ligament must be such, that it will act as a tightening arrangement at the close of the movement, and on further movement in the same direction ~~will~~ be further tighened ~~and~~ so as ~~will~~ further to force the articular areas into coincidence and so act as a checking mechanism. This checking action of capsular ligaments has constantly been defined as the main factor in the production of stability at an enarthrosis, in virtue of their non- extensibility beyond the maximum of movement. That is, that when the ligaments are fully stretched they of themselves would hold fast the bones in position, in what must be a sudden onset of action, and irrespective altogether of any possible definite relationship of the joint surfaces to one another. We have, on the other hand, put forward the view that the checking capsular ligaments are structures accessory to the production of a congruity of the opposing joint surfaces, and when the movement is terminated the joint cannot break its fully established congruity except in a direction reverse to its inception. The stability of the joint certainly depends on the presence of the capsular ligaments, but these are guiding agents in the production of a gradual progressive 'locking' of the joint surfaces themselves and then being fully stretched and in action they act as the tightening arrangements of the combination of the articular surfaces.

2. THE ACTION OF THE LIGAMENTS OF THE HIP JOINT.

The attachments of the capsule of the hip joint are such that a spiral twisting of its fibres takes place in the primary movements from the mid position in either direction, fig. 7: so that at the completion of extension the capsule is relatively shortened, and so much so that the head of the femur is forced to its maximum extent within the acetabulum.

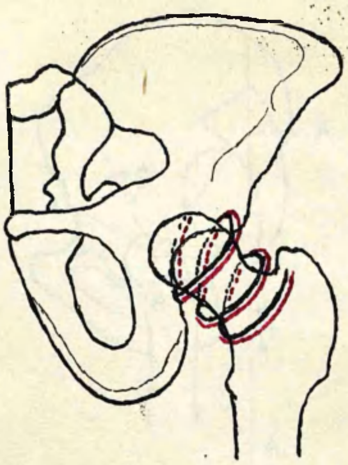


Fig.7

Scheme of band action at the left hip joint - a right winding screw. (after ALBERT).

In this position movement in this direction is terminal, and stability is ensured in the action of the capsular checking arrangements, the ilio-femoral ligaments. In the reverse direction towards semi-flexion the ilio-femoral ligaments become slack, and when the thigh has passed so far forwards and inwards, for instance ~~as it is~~ when the foot comes in contact with the ground in walking, the ligamentum teres and the pubo-ischio-femoral ligaments become tightened. The lig. teres is the internal lateral ligament, and the other bands of the capsule are the modified parts of the external lateral ligament of the reptilian hinge joint, the former having retained its incidence of action at mid position while the latter is, in part, a terminal checking mechanism.

Individually the ligaments functionate as follows .

A. The ilio-femoral ligaments:- The action of the lateral part of this ligament is understood best by a reference/

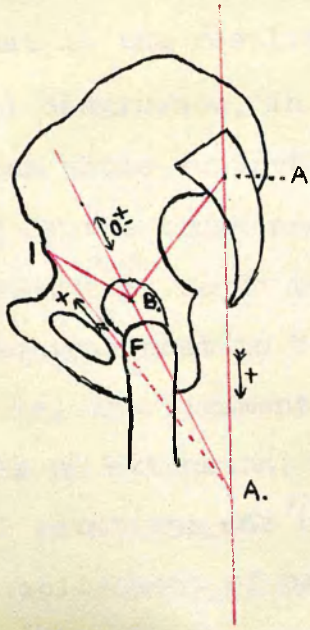


Fig. 8.

reference to a diagram of MEYER'S.(Fig.8.). The centre of grav:
:ity of the whole body lies opposite the 2nd.sacral vertebra in
the vertebral canal so that the line of body gravity (A-A.),verti:
:cal through this point, falls behind the interacetabular axis
(B-A.). In the erect position there is thus a constant tendency
to retroflexion of the whole pelvis but this is prevented by the
tightening of the lateral ilio-femoral ligament (1-F.). The
action of these two forces, the weight of the body (A-A) and the
pull of the ligament(1-F-A.) is common on the interacetabular axis
(B-A) and the result is the establishment of body equilibrium on
that axis by that forcible and positive contact between the heads
of the femora and the acetabula which is termed congruence, and
which in this instance is terminal so that no further movement in
the direction of extension of the femur is possible. The ligament
also/

also is tightened, that is the results of its action are observed as productive of terminal congruence, in the other body movements of the act of walking when the whole support is one limb: namely, the tendency to the inward rolling of the trunk over the supporting femoral head, and the rotation backwards such as tends to occur at the moment when the supporting unit is required most to be stable. As applied to the femur, as it usually is, the ligament is brought into action at the close of the movements of extension, of adduction of its lower extremity, and of external rotation: ~~and~~ The result of its action of course is as before, the establishment of osseous joint congruence; it does not by directing ~~of~~ the movements of the opposing surfaces on one another, but by so forcing those surfaces into ~~[illegible]~~ closer and closer contact, that they execute those movements, which are dependent ~~only~~ on the reciprocity of their configuration, ~~which are determined terminal in their ultimate~~ complete congruity ~~and~~ beyond which the ligament is inextensible.

The medial ilio-femoral ligament, lying as it does in the femoral axis, is an active accessory to the former ligament in 'checking' only the retroflexion of the pelvis,- or the extension of the femur

In conclusion it may be remarked that the breaking point of these 'checking' ligaments is greater than that of the bones to which they are attached, so that the stability of the joint is ensured above the fracture of its osseous components.

B. The ligamentum teres:- The action of the lig. teres has given rise to more controversy than perhaps any other structure/

structure in the human body, but the following are the main theories which have been advanced.

1. A number of authors ascribe to it no mechanical function, but regard it only as a means on which blood vessels may be led to the head of the femur, (HENLE, SAPPEY:) some em:phasise the greater importance of this function in the foetus. We consider this view later.
2. That the ligament secretes synovial fluid and distributes it over the head of the femur by its rubbing on the bone during movement. It cannot be said that the ligament does not secrete synovia since it is invested with synovial mem:brane, but it is certain that it persists neither for that purpose nor to act as a sort of 'wiping' or 'duster' mech:anism.
3. Strong isolated bands only develope, and persist, under the influence of pull or tension forces so that the ligament must be in action, that is stretched, during certain positions of the joint. These positions have been described variously and in vast detail, (HUMPHREYS, FICK, SAVORY, BRAUNE, STRUTHERS, etc.) but persistently from the point of view that the liga:ment acts as a 'checking' mechanism, that is that in its action certain movements are terminated. By direct observa:tion the majority of writers have described the ligament as most stretched in different secondary accompaniments of the position of semi-flexion; and of these secondary move:ments/

movements a combination of adduction and internal rotation (FICK) or external rotation (STRUTHERS) will render the liga: :ment most tense.

4. According to a fourth view (BARKOW) the ligament is most active in the foetus, retaining the femoral head within the flattened acetabular socket. Against this view, however, is the fact that in the position of the foetal limb the ligament is not stretched, and again, as has been previously indicated, the ligament undergoes positive development after birth.

If the ligament is to be attributed with a ligamentous function it is important that the exact position of its attachment on the head of the femur should be noted. If the bone is placed in the position it occupies in extension of the limb it will be noted that the line of attachment is situated obliquely between the vertical and the horizon: :tal, and that this line becomes purely horizontal when the limb is flexed to rather less than 45°. That the position of this attachment is mot wholly postero-inferior has already been indicated by the detail: :ed descriptions of GOODSIR, of STRUTHERS, and of MEYER. The exact position of the teres attachment is shown in figure 9 the bone being

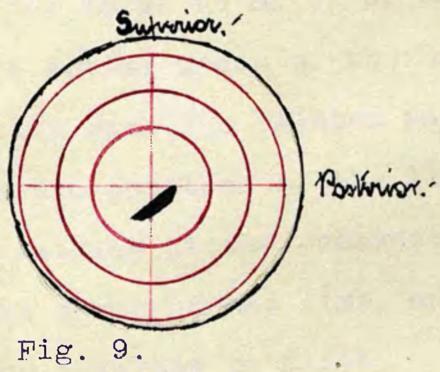


Fig. 9.

To show the attachment of the lig. teres.

the bone being in the erect position; while figure 10 demonstrates the relative change of position accompanying certain movements of the joint.

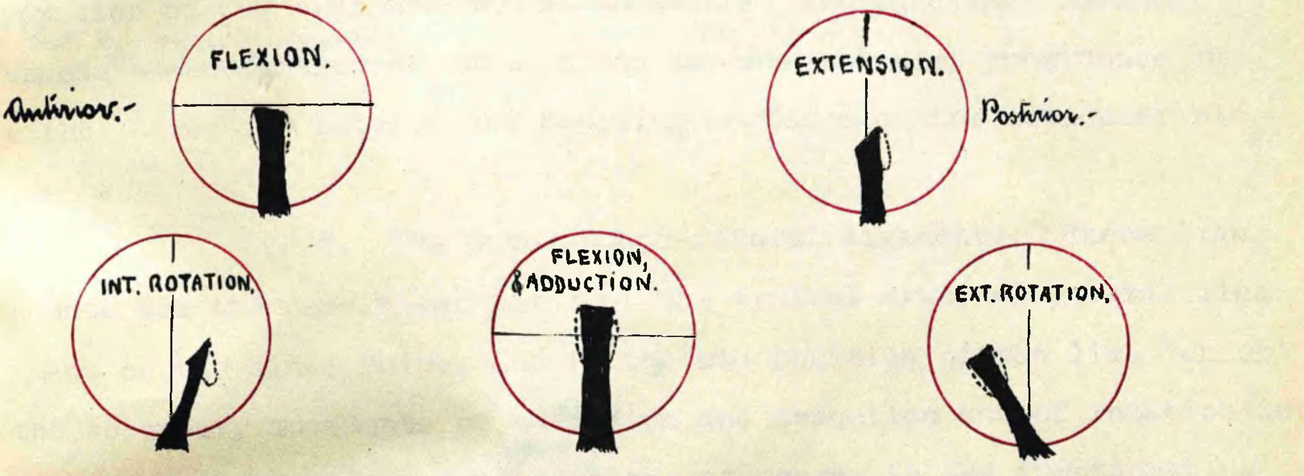


Fig. 10.

The change of position of the teres attachment in different movements of the joint. (after STRUTHERS)

The femoral attachment of the lig. teres is thus situated at a definite position and in a definite manner; in position, ~~as will be shown later~~, at the osculation of the two areas of which the head is resolved a component,(1) and in manner so as to allow of the fullest degree of activity when these two acting areas of the head of the femur are in the mimimum of congruity with the related passive areas of the acetabulum, that is at the mid position of the limb. And this position is that which occurs in walking at the commencement of the reception of the body weight on the outstretched limb, and is a combination of flexion, adduction and external rotation. The two parts of the lig. teres/

1) These areas will be defined later on.

teres, we believe, represent the typical formation of the lateral liga:ment of a hinge joint and are related to the two acting areas of the head of the femur and of the acetabulum; ~~and~~ Its action is at the mid position of the limb; and not ~~in the nature of~~ it does not operate by 'checking' movement but by maintaining ~~beyond the retention of~~ contact and regulating ~~the direction of~~ congruence in either direction between the opposing surfaces of the articular ele:ments.

C. The pubo-ischio-femoral ligaments; These liga:ments are the persistent parts of the typical external lateral liga:ment of the hinge joint, and in the mid position of the limb 'check' the secondary movements of adduction and abduction and of rotation in both directions in a manner similar, of course, to the functionating lig. teres.

D. The zonular band; On account of its fusion with them the longitudinal bands the zonular band ~~this one~~ must follow ~~these~~ in the movements of the femur; ~~and~~ acted on by them ~~in~~ the spiral twisting of the whole capsule, it grasps firmly the neck of the femur and fixes ~~it~~ the bone in contact with the acetabulum in the position of full extension.

PART THREE.

'THE FEMUR AND THE ACETABULUM IN RELATION TO THE HIP JOINT".

A. STRUCTURAL ANATOMY.

1. GENERAL ANATOMY OF THE PROXIMAL EXTREMITY OF THE FEMUR.

A. The Head;-The superior articular constituent of the femur,- the caput femoris,- is a mass of cancellous, cartilage-covered bone, and forms the male or active element of the hip joint. It is generally described as being that part of a perfect sphere ~~of~~ with a radius of twenty four to twenty six m.m. which would be subtended by an angle of about 326°. The question of its exact curvature is considered later. As regards the actual size of the head this depends just exactly as to where the plane of the measurement is placed, for as is shown in a subsequent section the margin of the head is not only not regular, but is even inconstant in its irregularity. As a general rule sections in a coronal plane are a little less extensive in circumference than sections in an antero-posterior plane, and on an average the radius is about 24 m.m. in the male; but almost diagnostic of the sex of the bone is the length of the diameter of the head. The average diameter measurements of 40 sexed bones were;

Male,....	4.71 cms.	.....(4.5 - 5.1.cms.)
Female,..	4.15 "	.....(3.8 - 4.3 ")

The diameter of the largest female bone is thus smaller than the diameter of the smallest male bone, so that absolutely and relatively the head of the femur is smaller in the female than in the male.

This is almost an absolute rule.[1] Other details of the head of the femur form the subjects of subsequent paragraphs.

B. The trochanters;- The femoral trochanters,- the great and the small, - can be considered for the purposes of the present study only as bony excresences of distinct epiphyseal origin for the attachment of muscles, and imposed on the main mechanical column,- the diaphysis of the femur. Thus in tracing the transmis:sion of weight from the head of the femur to its lower end, the essential static structure may be represented as in fig.11. (black outline). The further consideration of this conception is referred to the section dealing with "the inter:nal structure of the femur."

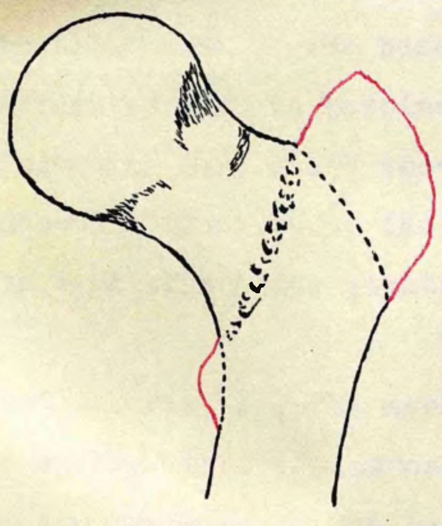


Fig.11
To show the trochanters as epiphyseal structures on the main static column of the femur.

It is possible however, as is already well known, to refer to the trochanter major those movements of the head of the femur undergone on flexion and extension of the limb. For, the highest point of the great trochanter lies almost on the same horizontal plane as the centre point of the head, to be exact usually a few millimeters higher, and this point of the trochan:ter can be determined with a consider:able degree of accuracy in the living person and in the cadaver owing to its superficial position.

1. Vide. PARSONS, Jour.Anat.Phys. Vol.48.p.253. and Vol.49.p.345.
DWIGHT. Amer.Jour. Anat. Vol.4.p.19.
HODGE, Assoc.Amer.Anat.Decr.1897.
DORSEY. Bost. Med. Surg. Jour. 1897.

C. The Neck:- The neck of the femur is a flattened arc of bone connecting the head with the upper end of the shaft, passing inwards, upwards, and forwards from the shaft at angles of inclination and declination of individually varying mag:
:nitude. The flattening of the neck is from before backwards and it is narrowest at its middle part,[1] expanding at both extremities but more so at its outer end where it becomes continuous with the shaft. The vertical diameter of the outer end derives its increase partly from the manner in which the lower border of the neck passes downwards into the inner border of the shaft, (Adams' arch), though in addition the whole neck here undergoes an enlargement in all its dimensions. The inner extremity of the neck is more circular in conformity with its attachment to the base of the head, the demarcation being best defined by what is hereinafter termed the "base line of the head", a limitation more exact than that advanced by HOFFA. (vide post.) The lateral limitation of the neck and its actual length as determined by its axis within its limits are fully considered later.

Taken as a whole, and as seen on horizontal section, fig. 12, the neck has a slight curvature with the convextiy forwards,- that is, opposite in direction to the curve which is found at the junction of the base of the neck with the upper end of the shaft.

1. An interest fact has been determined by TURNBULL(B.M.J.) Decr.1913. in comparison of the variation of the thickness of the neck and of that of the shaft. In support of the hypothesis that the range of deviation from the mean value will vary directly as the strain per unit volume TURNBULL found that there is a greater deviation of the thickness of the neck than there is of the shaft. The results are based on the measurement of 1800 femora.

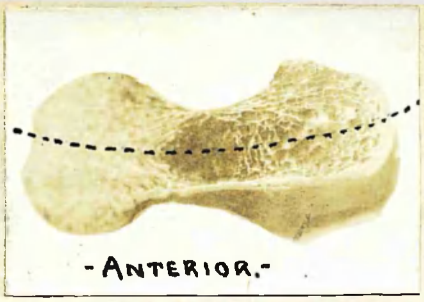


Fig. 12.
Horizontal section of the neck and head of the femur showing convex:
:ity forwards.

The anterior <u>surface</u> of the neck extends from the base line anteriorly to the external limit of the anterior intertrochanteric roughness. For descriptive purposes this surface is here divided into two parts, an outer smooth area and an inner rough area separated from one another by a hitherto undescribed ridge.(figs.13.14.15.) This ridge is constant in position in all adult bones though it varies within wide limits as regards its degree of evidence. In direction it is transverse to the long axis of the neck, parallel to the anterior intertrochanteric line and distant from that line about 1.5 to 2.0 cms. It is best marked towards the upper border of the neck, beginning as a rule abruptly just below the superior border, passes downwards and inwards with a concavity direct:
:ed upwards and inwards, and terminates below by gradually fading away into the general contour of the bone about half way down the neck It is thus early to be insisted on that this ridge is not merely the external limit of the medial rough area, but represents the internal boundary of and belongs to the lateral smooth area. The whole evidence of its causation demonstrates this fact. The lateral smooth area is almost comparable to the pulley on the lesser sacro-sciatic notch/

Ridge.

- Fig. 13.-

The proximal extremity of the femur, showing the "capsular ridge in a slight degree of development.-

Ridge.-

Fig. 14.

More advanced development of 'capsular ridge'.

Ridge.-

- Fig. 15.-

Well marked 'capsular ridge'

notch over which the tendon of the m. obtur.inter. plays at its exit from the pelvis; indeed in many specimens examined in the recent con:dition the whole formation of the superficial structure presents an almost identical appearance. A cartilage covering was never noticed in this position. On this smooth area there plays the supero-later:al part of the anterior capsule especially thickened in precisely this position as the most massive portion of the zonular band. In full extension of the limb - the position of greatest tension of its fibres - this part of the capsule acts in such a spiral manner as to produce this "capsular groove" and its medial boundary the "capsular ridge". An examination of a series of fresh specimens shows how close is the relation between the capsular development and the degree of evidence of the capsular ridge and the marking off of the capsular groove. In young bones no such ridge is to be found nor for that matter is there any indication of an anterior intertrochanteric line. It is about the age of 18 years that the roughness at the anterior capsular attachment begins to appear: it is progressive in develop:ment yet varies with the amount and strength of the capsular fibres. Only subsequent to that period can evidence of the capsular ridge be found, and it is always best marked when the capsule and its attach:ment are well developed. BERTAUX held that the roughness on the anterior face of the femoral neck was due to the partial attachment of the fibrous capsule, a view somewhat similar to that more recent:ly advanced by FRASER, who holds that the roughness is due to re:current fibres from the anterior circular set of capsular fibres.

Now,/

Now, it was dogmatically insisted on that in the region of this groove there is no recurrence of capsular fibres back on the neck, neither in the foetus nor at any subsequent period: no matter into how many layers the capsule be split each layer which has a femoral attachment at all is fixed in the region of the anterior intertrochanteric line, the retinacula being placed in their entirety either proximally or distally to this area. This lateral area, then, devoid of vascular foramina is a pulley on which there plays the upper and outer part of the anterior capsule, and contact is closest when the limb is in full extension. These facts are made clearly evident if the finger be placed on the groove through a slit in the complete capsule and the limb slowly extended from the position of flexion.

For the full appreciation of the medial rough area of the anterior surface of the femoral neck reference must be deferred till the consideration of " the cartilaginous margin of the head of the femur".

The whole anterior surface of the neck is perforated by numerous vascular openings situated for most part near to the base of the head in a superior and inferior group, fewer in number towards the anterior intertrochanteric line but completely absent in the capsular groove.

The posterior surface of the neck is over all as smooth as the lateral part of the anterior surface and is broader and more concave. As measured from the base line of the head to the posterior intertrochanteric ridge it is longer, on an average about 1.2 cms., than the anterior surface. Passing almost transversely across/

across it there can be distinguished a broad groove which lodges the tendon of the m.obtur.exter. The capsular attachments have been con:
:sidered and from that study there is nothing to be deduced from the manner of the arrangement of the capsule fibres to account for the absence of a ridge at the posterior capsule insertion. The only differences between the anterior and the posterior sets of fibres are in the greater strength and the greater amount of pull exercised by the anterior set. In support of this quantitative as opposed to any qualitative causative factor, such as has been advanced, there may be cited the facts already given as to the ontogeny of the anterior roughness and in addition its absence in those mammalia in which there is an absence of the anterior ligaments and the presence of a roughness postero-superiorly at the insertion of the active capsular ligaments when these are on the dorsal aspect of the capsule.

The posterior surface is also perforated by numerous vascular foramina, and again these are most numerous towards the margin of the head at its upper and lower parts.

2. THE CARTILAGINOUS MARGIN OF THE HEAD OF THE FEMUR.

The articular margin of the head of the femur is un:
:dulating; in a regular and constant manner as regards the incidence of the causes of the unevenness though in degree variation does occur to a considerable extent. The undulations are excursions outwards of the articular cartilage and between these recessions inwards, or more correctly, recessions where the extension of the cartilage towards and over the neck is more limited in extent. The most marked inward con:
:cavity/

concavity of the articular margin is placed opposite the great trochan: :ter towards its posterior part, and bounding this concavity are two outward eminences one towards the back and one towards the front of the neck of the femur. Of these the posterior is more localised and angular than the anterior and in size is much the more constant: for a series of femora may be found, even among European races, in which the anterior of these excursions is continued for some considerable distance over the neck of the femur. This variation was described by HENKE but no special significance was attached to it. FICK describes it as 'the emmenentia articularis colli femoris': CHARLES writing on this same structure from a study of Hindu bones attributes the condi: :tion to an adaptive variation dependent on continuous overflexion of the joint such as occurs in the 'squatting' position. He claimed the condition as essentially Asiatic, and described the European femur as having an even articular margin when looked at from above. Neither of these conclusions can be held as correct: Indeed, PARSONS has been able to find evidences of marked unevenness in over 60% of English femora. POIRIER and CHARPY in discussing this structure point out that the head is continued down on to the neck anteriorly and poster: :iorly, while on the anterior face of the neck there is a rough im: :pression, 'd'empreinte iliaque', which is occasionly present as a continuation of the articular cartilage of the head. These authors explain the condition (the roughened surface) as being due to the con: :tact of the neck of the femur with the superior part of the acetab: :ular margin in the position of extreme flexion: but, as FICK has pointed out, considerable abduction combined with internal rotation would be necessary before this contact could take place, and PARSONS' figures/

figures emphasise the incongruity of the correlation when heed is taken of the unnaturalness of the required position.

The medial area of the femoral neck may be found to exist in three different structural conditions, rough in about 70%, almost smooth in about 20%, and in the remaining 10% more or less cartilage covered. While the anterior cartilage excursion thus varies to a considerable degree yet its lateral margin will never be found beyond that definitely marked ridge on the neck of the femur, previously termed the capsular ridge. Even in advanced cases of rheumatoid arthritis though the marginal bony outgrowths may bridge over the capsular groove so as almost to convert that groove into a canal yet the attached base of the osteophyte does not extend on the neck lateral to the capsular ridge. Now, on closer examination of this excursion in its extreme degree it is clear that the cartilage is not in physiological continuity with the articular surface from which it springs, being curved in one direction only, antero-posteriorly, but perfectly flat in the latero-medial plane. In addition to this fact, we have never been able to find an absolutely smooth surface on one of these extreme excursions. They have never presented themselves in the young subject. and always, in this series, they have been associated with strong bony ligamentous markings and with powerful capsular bands. Further in no possible natural position in any of the joints could this excursion, in any of the specimens in which it was present, be made to enter the acetabular cavity: in other words, when the anterior excursion of the cartilage from the head over the neck is present to an extreme degree the lateral part of that excursion is never intra-articular in the sense/

sense of lying within the acetabulum. It must therefore be concluded that this condition is simply a variation of the more commonly found roughness, which, as already indicated, is placed medial to the capsular ridge.

In considering what the cause of this roughness may be, it is necessary first to define the usual relationship of the tendon of the m. ilio-psoas to the proximal extremity of the femur, and especially in the position of full expension. (fig.16.) The tendon of the m. psoas is medial to the vertical limb of the ilio-femoral band above so that when the bursa under that tendon communicates with the cavity of the hip joint it does so medial to that ligament and exposes the lateral part of the anterior cartilage of the head of the femur. The iliacus muscle, laterally placed, lies much more on the femoral neck over the vertical limb of the ilio-femoral ligament, but it

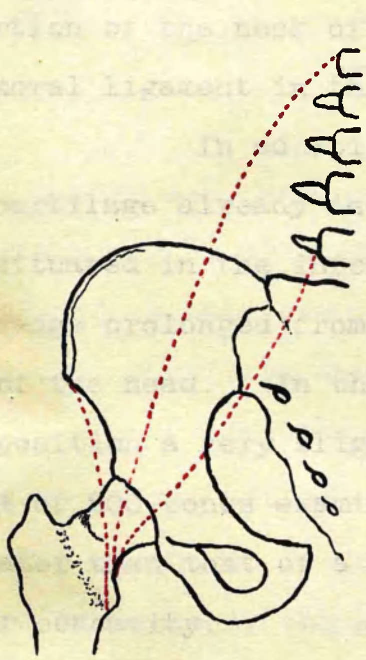


Fig.16.
To show the usual relationship of the ilio-psoas mass to the proximal extremity of the femur.

will be noted that the direction of the concavity of the combined mass is upwards and outwards. Thus any action which the ilio-psoas may have on the production of markings on the neck of the femur would not only/

only be confined to the lower part of the femoral neck, but there only after acting through a structure more powerful and of greater extent than itself, the medial part of the ilio-femoral ligament. The ilio-psoas, therefore, cannot be held responsible for the marking in question. It is also clear from its extent that this medial rough area, or its variations, does not result from bony contact with the margin of the acetabulum; and the conclusion seems justifiable that the structural condition of the whole area represents the amount of contact of this portion of the neck of the femur with the vertical limb of the ilio-femoral ligament in the position of complete extension.

In addition to the two outward eminences of the articular cartilage already indicated there was described by GOODSIR a third, situated in the inferior shallower concavity at the intersection of the ridge prolonged from the lesser trochanter with the articular margin of the head. In this series a little anterior to the above defined position a very slight outward projection was found in less than 10% of 200 bones examined on this particular point,-a frequency not greater than that of a small outward eminence in the middle of the superior concavity.

WAGSTAFF was the first, we believe, to describe the outline of the head as being sinuous or in curves and to coincide these excursions of the cartilage to the limits of the acetabular margin in differing positions of the femur. He detailed three such curves (fig. 17.) and related them to the limits of movement as follows:-

1. Inferiorly, - limit of adduction.
2. Posteriorly/

2. Posteriorly - limit of ext. rotation.

3. Anteriorly, - " " int. rotation.

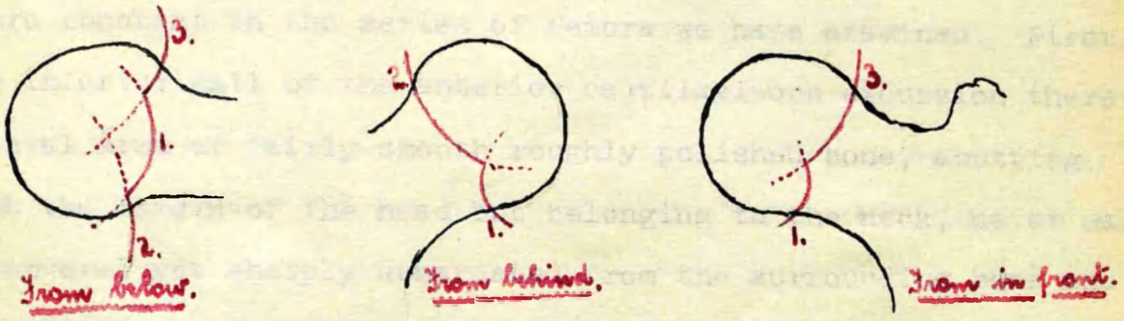


Fig.17. (after WAGSTAFF.)

We would rather say, however, that from its articular margin the head of the femur may be divided into two areas, anterior and posterior when the bone is held erect, and that each possesses a prolongation of the articular cartilage downwards over the neck.

In tracing the ontogenetic changes which occur in the outline of the articular margin it is to be noted that even in a foetus of 5 months it is possible to determine anterior and posterior cartilage excursions, though not developed ~~nothing~~ to anything like ~~to~~ the same extent as in the adult. The margin is thus much more even and circular than at later periods. From the beginning the cartilage must be held to grow, not only in the relative sense but also absolutely down over the neck of the femur, producing the irregularities of outline and as is indicated later, bringing the diaphyseal neck into the formation of the central core of the articular head. In this connection it may be emphasised that an uneven articular margin should be taken as essen-:tially/

essentially a human characteristic contrasting strongly with the even articular margin of the anthropoid apes.

Two other markings at the margin of the head of the bone are constant in the series of femora we have examined. First, on the inferior wall of the anterior cartilaginous excursion there is an oval area of fairly smooth roughly polished bone, abutting against the margin of the head but belonging to the neck, never carti:lage covered yet sharply demarcated from the surrounding bone and differentiated by the absence of vascular foramina. This marking is produced by bony contact with the margin of the acetabulum. It is intra-synovial in position, - that is, the synovial membrane ceases at its lateral border. Contact takes place between this portion of the neck and the articular margin at the anterior part of 'the pubic protuberance of the acetabular rim' in the position of complete exten:sion. In this position extension is combined with a certain degree of external rotation which takes place primarily to allow the most complete reception of the head of the femur within the acetabulum, and to produce secondarily the locking of the knee joint. When the femur is thus extended and rotated the anterior excursion of the ar:ticular cartilage of the head is in firm contact with the lower part of the iliac area and with the pubic area of the acetabulum, while the imprint described is forced to rest on the latter area at its margin:al part. It is therefore proposed that this 'facet of rest,' or, 'pressure facet', should be termed the "pubic imprint". In extent the pubic imprint varies a good deal, but a well marked bone would show it as about 1.5 cms. long, about .8 cms. at its broadest part, of oval form but tapering away inferiorly, an incidence in conformity with its incidence of action. At twelve years this marking is per:fectly/

perfectly distinct, though it is relatively smaller than in the adult, but previously to this period it cannot be determined with any degree of accuracy, and is certainly absent up till the sixth year. Second, the excursion over the posterior part of the neck is, as previously stated, more constant in size than the anterior excursion. It is wholly acetabular in position when the limb is completely extended, occupying in that position the 'ischial projection' of the acetabulum. By its upper border it bounds the superior concavity posteriorly, and the bone lying lateral to this boundary corresponds in structure to the pubic imprint. Thus it is proposed to describe another 'pressure facet' on the femoral neck, constant in position and, though varying a little in size, of dimensions on the average very comparable to those of the pubic imprint. This facet, differentiated by similar structural characteristics, is produced in like manner to the pubic imprint- that is, by contact with the acetabular margin. It is probably differentiated at a later period of life. In respect that contact takes place with the ischial part of the acetabular rim the facet may be termed the 'ischial imprint', These two facets, pubic and ischial, represented in figs.18 and 19, are most evident in the recent specimen;

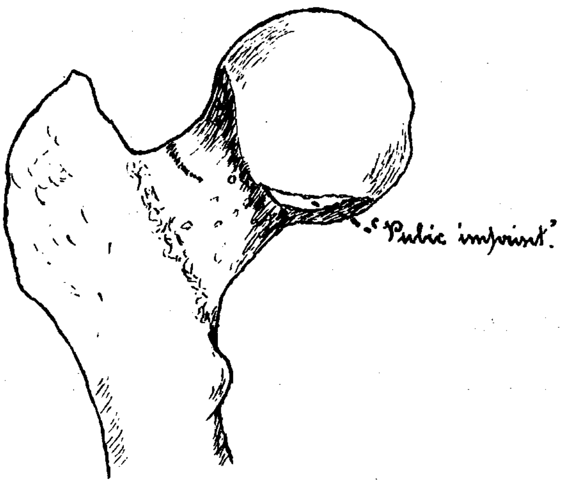


Fig. 18.
Proximal end of femur viewed from the antero-lateral aspect, showing inferior to the anterior cartilage excursion the 'pubic imprint'. Founded on an examination of over 300 bones, The anterior cartilage excursion is represented in its normal amount.

and it is important to note that in situation they are not on the epiphysis of the head but on the diaphysis of the shaft, so that con:
;tact at these points will not in any way bring abnormal strain to bear on the epiphyseal plate while that is still cartilaginous.

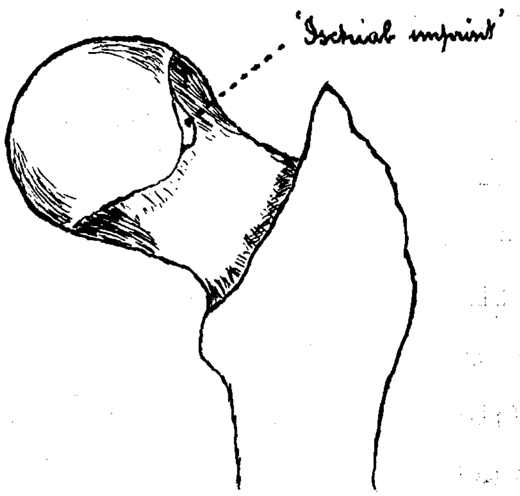


Fig.19.
Proximal end of femur from posterior aspect showing the 'ischial imprint'. Founded on an examination of over 300 bones.

3. THE EPIPHYSIS OF THE HEAD OF THE FEMUR.

So far as the writer is aware there is on record no detailed description of the epiphysis of the head of the femur,- that separate centre of ossification in the continuity of the cartilaginous 'Anlage',- apart from the usual statement that the mar:
;gin of the articular cartilage of the head represents the position of the epiphyseal cartilage.

At birth, as is well known, the femur is os:
;sifying in its diaphyseal portion, the lower epiphyseal centre is usually/

usually present, but the whole of the upper extremity of the femur is as yet one undivided mass of cartilage, - the tri-epiphyseal cartilage. (fig.20). In this upper cartilage appear ossific centres, for the head towards the end of the first year, and subsequently for the trochanters. In the consideration of that centre which ossifies as the articular portion of the head of the femur, there will fall for study the shape and change of shape of the epiphysis, the position and the change of position of the epiphyseal cartilage, the effects of these changes in addition to their causation, and subsequently of this especial epiphysis the blood supply will be detailed.

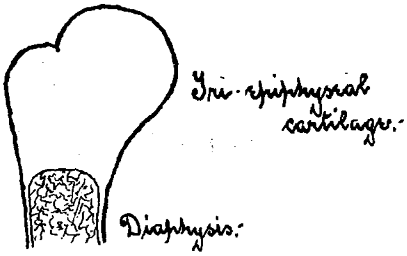


Fig.20.
The proximal extremity of the femur, at birth.

The ossific centre for the head, often surrounded by a number of small osseous granules, appears then a little earlier or a little later towards the end of the first year[1] and the position of its earliest occurrence is above and medial to the centre point of the whole head. (Fig.21.) After the appearance of this ossific centre, the head, still mainly cartilaginous, is connected with the great trochanter by a thick mass of epiphyseal cartilage: but after differentiation of the trochanter as a separate ossification/

1. This centre may appear at the 10th. month or may be absent at the 13th. month.

ossification these two epiphyses are gradually separated from one another by the growing diaphyseal neck, and subsequently increase in size quite independently of one another. By the end of the fourth year nearly the whole of the epiphysis of the head is osseous, the cartilage now consisting only of the thin dentate epiphyseal car:tilage separating the head from the neck. At seventeen years the epiphy:sis is fully ossified, and finally joins the diaphysis about nineteen to twenty years, though a line of separa:tion often exists at the circumference, especially at the lower part, even with firm osseous union at the centre. On section a line of dense bone persists for some years, indicating the line of cartilaginous union. Taking, however, a section through the head parallel to the articular margin but medially distant about one centimetre, such as is represented in fig.22., at about twelve years of age, there is clearly shown the large part taken by the diaphyseal neck in the formation of the/

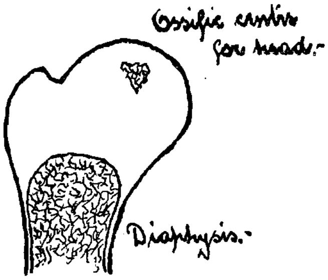


Fig.21.
The ossific centre for the epiphyses of the head, at 11 months.

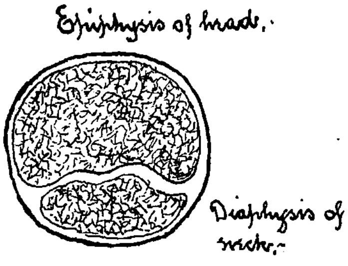


Fig.22.
Section through the head of femur, medial and parallel to the articular margin at 12 years.

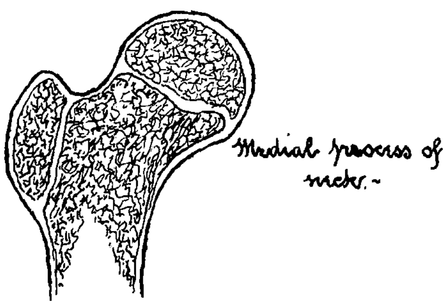


Fig.23.
Vertical section of femur at 12 years.

the centre core of the head, and the peculiarity of the manner in which it does so. This peculiarity consists of the greater proportional representation of the diaphysis at the under part of the head as compared with the upper. An examination of the upper surface of the diaphysis is explanatory of this peculiarity, for on reference to fig. 23 it is shown that the inner end of the neck projects above the general plane of the rest of this diaphyseal surface. At this age (twelve years,) the diaphysis of the neck forms a central core ~~down~~ over which the articular surface of the epiphyseal head extends: not in a regular fashion, however, but yet so as to embrace the upper end of the neck in a circularly complete manner. It will also be noted, and more especially at the period immediately previous to the bony union of the epiphysis with the diaphysis, that both ossifying surfaces are irregular; and the irregularities are so arranged and of such a shape, that small hemispherical nodosities of the upper surface of the neck are occupying small concavities of the under surface of the head. While the under surface of the epiphysis of the head is thus concave in all directions, it is most deeply excavated at its application to the medial process of the neck, and the extension of the epiphysis over the diaphysis is in this situation the most limited. (MACALISTER has already pointed out how the thin irregular rim from the head extends outwards over the upper part of the neck, and assists in the transmission of weight from the head above to the calcar femorale below.). From a morphological point of view, however, it is more important to recognise that the lower aspect of the epiphyseal rim extends to the least extent over the diaphyseal neck, that it is the thinnest part of the whole epiphysis, and that it is the last portion to become osseous.

On/

On tracing the ontogeny of this epiphysis, the diaphy: :seal spur at the medial extremity of the neck will be found to be best developed towards the age of puberty: and, though in the process of for: :mation it may be recognised at an earlier period of life, up to ~~till~~ the age of four years it is certainly non-existent. The advantage gained by such a process is the ~~in~~ preventi~~ng~~on of any undue tendency to luxation of the epiphysis, a tendency, as will be shown, at its greatest degree of mechanical possibility when this natural means of prevention arrives at its maximum of development. A comparison with the femur of the seal is instructive not only as regards the phylogony of the medial process of the neck, but also in assisting to a decision on ~~of~~ the morphology of the ligamentum teres of the hip joint. In the Ross seal the articular head of the femur is incomplete, so that the medial process of the neck is entirely a superficial structure.(fig.24.) That the ligamentum teres is isolated by the development of the head of the femur as a wing expansion on each side of the ligament, with subsequent fusion of the wings under the ligament at the lower part of the head, as stated by KEITH, seems strongly substantiated by the mode of development of the epiphysis of the head.

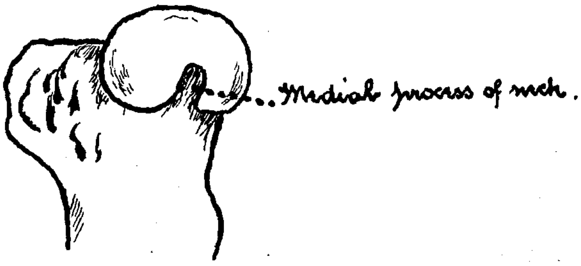


Fig.24
Head of femur or seal, (after THOMPSON).

N.B. The position of the epiphyseal cartilage and its change in position are discussed in the section on 'the axis of the head'.

4. THE BLOOD SUPPLY OF THE HEAD.

The blood vessels which enter the hip joint by passing under the transverse ligament of the acetabulum have been defined by all observers as arising from the external branch of the a.obturator and from the medial circumflex branch of the a.femoris. The work of SSAWWIN is the most detailed. He demonstrated by means of very fluid injections that the obturator branch anastomoses with that of the med: :ial circumflex to form two main vessels, one, the a.acetabuli,which formed a rich vascular network in the Haversian fat, the other not at all constant, the a.ligamenti teretis, which ran through the ligamen: :tum teres to the head of the femur. In some cases he found no vessel in the round ligament at all, in most a fairly well marked channel, and in a few specimens a double artery. The method adopted by the writer was one of differential injection with very fluid media, the anterior division of the internal iliac artery being injected with one colouring matter, and the rest of the body with a differently coloured preparation. By this means it was determined that running underneath the transverse ligament there is a large branch from the external division of the a.obturator, and a smaller branch from the internal circumflex artery. These two vessels united in the floor of the acetabulum and formed a network exactly as described by SSAWWIN, and from this network a small branch proceeded to the ligamentum teres.

Many authors hold, of course, that this is the sole function of the round ligament, to lead vessels to the head of the femur: (HENLE and SAPPEY both held this view.) After a most careful inquiry WELCHER came to opposite conclusions. On an analysis of thirty/

thirty cases he found that in 9 there were no vascular markings on the floor of the teres fossa: in 11 only one or two small pits: in 8 there were 3 to 6 foramina: in 1 ten, and in one twenty five small openings. HYRTL also upholds the view that the ligament does not convey blood vessels to the head of the femur, and claims to have proved that at the femoral extremity of the ligament the arterial ves-sel forms a capillary loop and runs back as the vein. For the present work about 100 round ligaments were examined for the contained vessel by means of a hand lens, yet no ~~a~~ vessel of any size was ~~not~~ found: there-fore it was concluded that not only is this vessel not the sole sup-ply, but that it only can convey a very trifling amount of blood to the head of the bone. On examination of the 'differentiated' specimens, numerous vessels were found ascending into the head from the articular margin, but not the slightest evidence of any vascular channel from the ligamentum teres into the neighbouring bone could be determined: that is, in the adult at least, the blood vessels of the ligament are not destined for the supply of the head of the femur. In support of this anatomical fact there is the finding of pathology, first in re-gard to dislocation of the hip and second in fracture of the neck of the femur. For the full development of the former condition there must be of necessity a complete rupture of the round ligament, yet after reduction of the dislocation it is never held that the head of the femur is defective in nutrition. A considerable amount of work is available in regard to fracture of the neck of the femur, and here the consensus of reliable opinion is that the condition of the liga-ment is absolutely immaterial, the rupture or non-rupture of the synovial and fibrous connections between the neck and head with the contained/

contained vessels determining the future state of the head.

Some writers hold, however, that it is in the child that the ligamentum teres as a means of leading vessels to the femoral head is in the fullest degree active, and after that period the blood supply is derived from the blood vessels of the diaphysis at the articular margin. (LANGE.). Against this view there are the very dogmatic statements of FICK and WELCHER. The former definitely states: "In the young subject the blood supply is not through the round ligament but through the vessels which enter the large foramina at the articular margin of the head". While the latter is equally certain of this view in the determined absence of vascular foramina in the teres fossa of the embryo and of young children.

For the present work two male children, aged two years and six years respectively, were prepared by the differential injection method already described. In the child of two years, - that is at a period when the ossification of the head is not to any extent advanced, - the blood vessels which passed to the osseous nucleus were derived in no part from those of the ligamentum teres, but entirely from vessels entering the neck of the femur at the articular margin of the head. These vessels are distinctly seen in their course to the centre of ossification lying in the lower part of the cartilage of the head, but a small area of the superficial cartilage above this centre and in immediate proximity of the attachment of the ligamentum teres did seem to be vascularised from the a.ligamenti teretis. (fig.25.). The specimen obtained from the child of six years (fig.26) also gave emphatic evidence that for purposes of ossification the blood supply is obtained, not from the vessels/

vessels of the ligamentum teres, but from those which enter at the

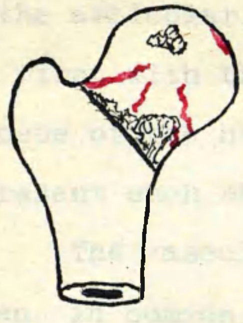


Fig.25.
Blood supply of the centre of ossification at two years of age.

Fig.26.
Blood vessels of the head at six years of age.

articular margin of the head and pass thence proximally through the epiphyseal plate to ramify in the osseous substance of the head. And when in addition it is determined that in cases of congenital dis:location of the hip the head of the femur undergoes no especial atrophy in the absence of the ligamentum teres, it may no longer be held that "the round ligament conveys a blood supply to the head of the femur".

As regards the foramina in the floor of the teres fossa the following alternative view as to their causation is advanc:ed. From the detailed examination of these foramina there is evident not only the inconstancy in number as described by WELCHER, but that the sectional area of the average number is out of all pro:portion to that which could possibly result from a subdivision of the a. ligamenti teretis: that is, that all of these openings cannot possibly be vascular channels. Now from a study of the method of attachment of the ligamentum teres to the head of the femur in the foetus and in the adult, it may be shown that, while the marginal parts/

parts of this ligament may become continuous with the superficial layers of the articular cartilage, the central parts are in direct continuity first with the cartilaginous and subsequently with the osseous tissue of the head. And the foramina, found only in the adult, represent such channels of communication.

The vascular supply of the epiphysis of the femoral head is then, in common with other epiphyses, derived from a special set of epiphyseal vessels entering the bone distal to the epiphyseal margin. At early periods of ossification these vessels form an entire and distinct circulation, and only subsequent to the osseus union of epiphysis and diaphysis do they anastomose with the intraosseal ves:sels of the shaft. Derived mainly from the circumflex arteries these branches perforate the capsular attachment, proceed medially superficially on the neck in two main groups and in relation to the synovial retinacula, and become intraosseal towards the articular margin of the head. The details of the intraosseous vessels are de:termined best by X-ray photographs of mercury injected specimens and by this means we have been able to confirm the work of LEXER.(fig.27).

From preparations by
Dr. J. Buchanan,
Demonstrator of Anatomy
Glas. Univ.

Fig.27.
X-Ray photographs of mercurial injected femora of a cat; showing course of intraosseal vessels to epiphysis of head.

5. THE FOSSA FOR THE LIGAMENTUM TERES.

The fossa at the femoral insertion of the ligamentum teres has in various places received various descriptions, such as round, oval, trifoliate, etc; even a percentage of the different forms has been detailed by BROCKWAY.

An examination of a large number of bones was made in order to demonstrate the relation of the attachment of the lig. teres to possible function, and the following conclusions were arrived at regarding the shape of the fossa.

If the femur be held so that the ridge joining the lesser trochanter and the articular margin of the head is vertical, then in every instance, and more especially in the recent condition, the fossa would allow of a reduction to the triangular form, and in this position of the bone the base of the triangle is horizontal and the apex points almost directly downwards.(1) The attachment of the ligament in this fossa is mono-linear, that is to the base alone, so that the lower apical part of the triangle is simply a depression of the articular cartilage which lodges the ligament when it is in a state of tension. If the bone be placed in the position it occupies in the erect posture it will be obvious that the ligament could not then lie in the fossa: for it is only when it is forcibly stretched that the ligament will be pressed against the head of the bone, and the position of the limb when the ligament is stretched is one of semi-flexion. In the foetus and in the young subject the linear attachment is very definite. In a 3 cm. embryo there is a relatively large flattened area on the head of the femur in the morphological position of the impression for the lig. teres of the adult, and at the/

(1) This corresponds to the form of the fossa which FICK describes as the normal.

the upper part of this the tissue of the ligament becomes continuous with the tissue of the head through a slit-like cleft (fig.5.). In a foetus of five months below and behind the linear attachment there is a relatively shallow depression in the head of the bone to which the liga:ment has absolutely no organic connection. At three years of age the depression is definitely triangular, gradually becoming shallower in the downward direction till it ceases altogether at the point where a vertical tangent from the acetabular attachment would touch the head. The attachment remains monolinear to the base of the depression and within its limits, though occasionally the cleft may be found pass:ing completely round the head as a groove and separ:ating the functional anter:ior and posterior articular areas. (fig. 28.).

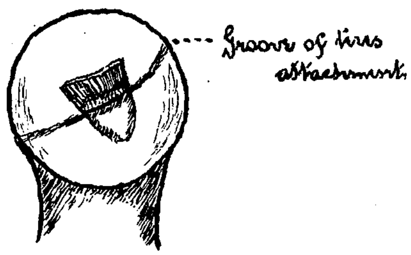


Fig. 28.
Head of femur viewed from spherical pole, to show the attachment of the ligament and the teres fossa at three years of age. In this specimen the attachment groove was continued round the head, a condition we have also observed at 12 years.

6. THE ARTICULAR CARTILAGE OF THE HEAD.

The articular cartilage covering the head of the femur, and as already indicated enclosing a considerable portion of the diaphyseal neck, is in common with other convex articular carti:lages thicker at its centre than towards its margin. A more minute examination demonstrates certain important mechanical points. Reference is made to fig. 29. Here it is shown that the greatest thickness is not/

not exactly at the centre of the head but below and anterior to that

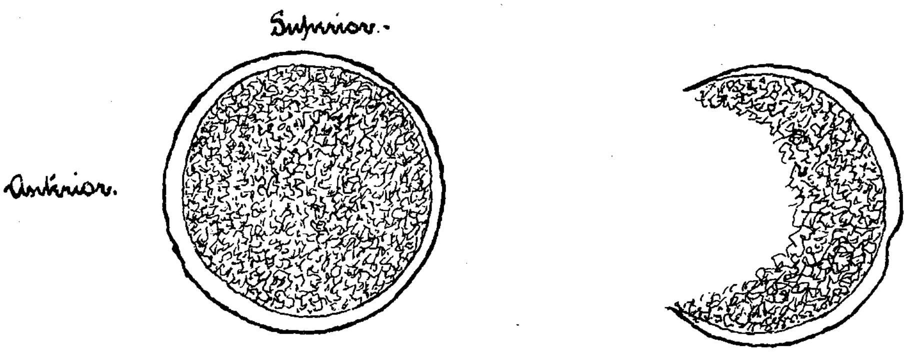


Fig. 29.
The articular cartilage of the head in section.

point, in the region of the teres fossa: and from there the cartilage decreases in thickness less quickly below and in front than above and behind. At its thickest part the cartilage is on an average 3 mms. on section, decreasing to approximately 1 mm. at the supero-posterior border, but it measures almost 2 mms. at the antero-inferior margin. Thus there is every indication that WERNER'S description is correct, "that during life the antero-inferior part of the margin is subject to greater pressure than the supero-posterior part of the margin".

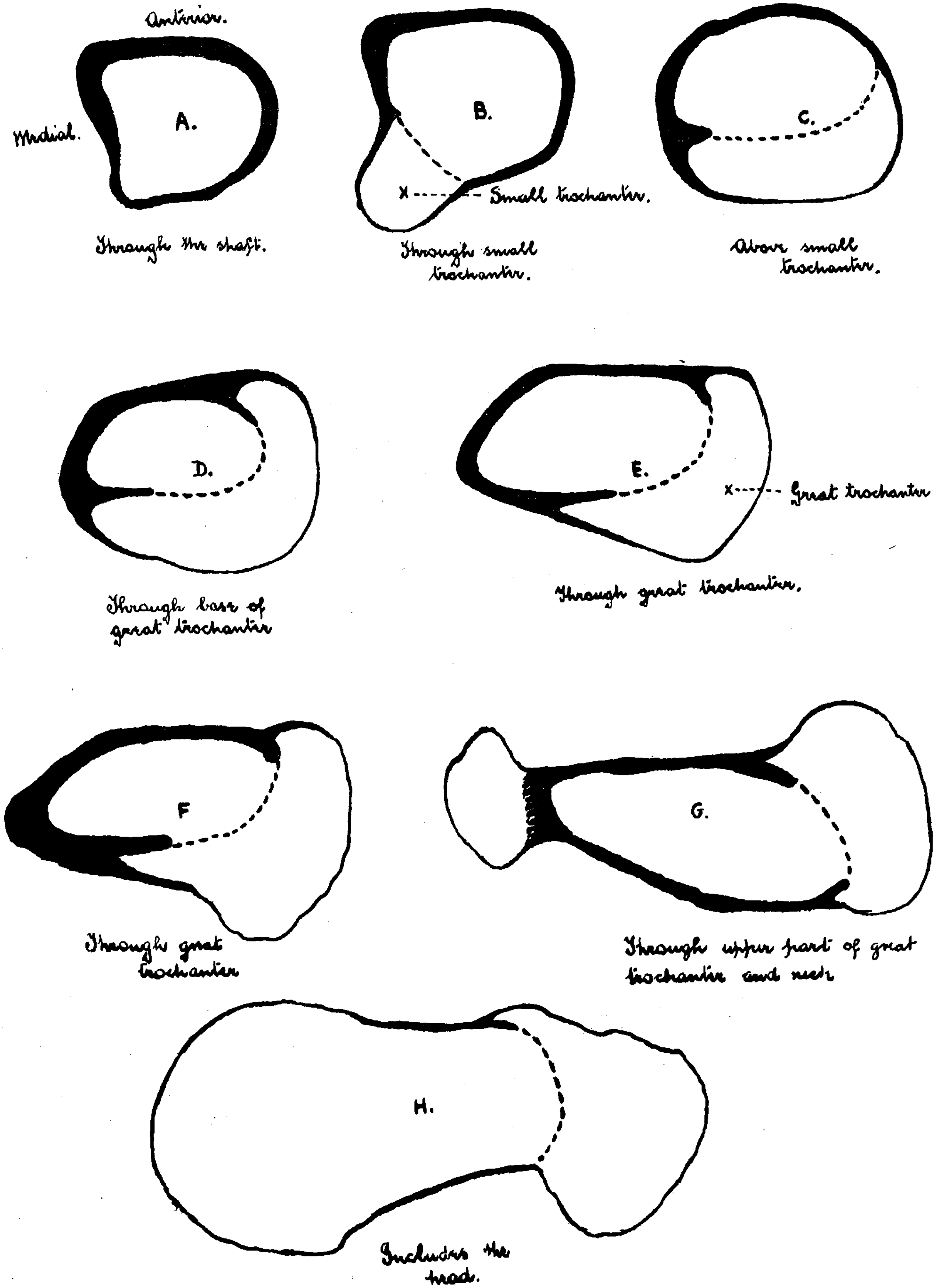
7. THE INTERNAL STRUCTURE OF THE FEMUR.

The proximal extremity of the femur consists of cancellous tissue, surrounded by a layer of dense bone. It is proposed only to define the view that has been adopted here regarding the rela: :tionship of compact and cancellous bone, and this view being mainly mechanical no question of morphological comparison arises. The spongiosa shows a well designed architecture which bears the closest relationship/

relationship to the statics of the bone: but so also does the compacta show the same well defined mechanical arrangement, - a fact, we believe, which has not yet been expressed with sufficient emphasis. The morpho:logical differences we hold to be the expression of the differences in the degrees of concentration and uniformity of direction of the main stresses through which the bone acts. In the compacta the con:centration is at the maximum and the uniformity of direction approach:es totality: but replacement by spongiosa takes place wherever there is a spreading out of the force for transmission to another element, or where the direction of the conducted force requires alteration to a new plane of transmission. From this purely mechanical point of view the compacta may be considered as compressed spongiosa and the spongiosa as delaminated compacta.

A. The compacta-; Over the major part of the extrem:ity the compact layer is only a thin surface lamella continued dis:tally into the superficial strata of the compact boundary of the shaft. The distribution of the compacat is most easily understood and its arrangement for mechanical purposes most easily followed, if an examination is made of a series of transverse sections of the bone from below upwards and a glass plate reconstruction of these sections is then examined. Such a series, obtained from an adult male bone, is shown in fig. 30. The section through the shaft (A) shows the com:pact bone as a circumferentially complete layer of a definite mech:anical strain bearing thickness. The greatest thickness is at the junction of the anterior and medial surfaces, where, in the complete bone, a very definite ridge mass passes down the shaft from the under side/

Fig. 30.
The distribution of the compact layer.



side of the neck. The lateral circumference takes a considerable part in the weight transmission but the posterior part only to a very slight extent and least of all. In the section through the small trochanter (B) it is very clear that this epiphysis takes no part in the formation of the mechanical axis of the shaft. The surface com:
:pact layer is a mere skin covering, and the thick compact layer of the medial surface turns lateralwards into the substance of the bone as a projecting ledge. The completion of the mechanical axis would be by the dotted line, beyond which the compact layer shelves very quick:
:ly away into the surface of the small trochanter. The projecting ledge of bone is the lower part of the 'calcar femorale',(C-F) (Schenkelsporn, MERKEL.) The succeeding sections (C-F) are through the shaft ascending from the base of the great trochanter, and the principles of structure as found at the lower epiphysis are adhered to. There is on the anterior and the medial surfaces of the bone a definite compact layer, imposed on which postero-laterally is the non-mechanical apophysis, the great trochanter. The compact static column behaves in an exactly similar manner at both of its extremit:
:ies - it is folded into the cancellous tissue of the muscular apoph:
:ysis in major part, and distal to this tapers away very quickly. The posterior of these infoldings is shown in its fullest formation in fig.F.,it is larger and of greater extent then the anterior fold:
:ing, and hence we find that the distal tapering off is more abrupt than that occurring distal to the anterior fold. This posterior fold, as already indicated, is the 'calcar femorale' described by MERKEL,and we propose to name the other fold 'the calcar femorale anterior'.

The/

The succeeding sections G-H involve the head and demonstrate the an: :terior and posterior retentions of compact bone on the neck, its absence from the great trochanter and the head, while the calcar fem: :orale anterior is seen to be developed at a higher level than the posterior one. The absence of medial infoldings of the compact wall in these sections is of course dependent on the fact that there is at these positions no main static column, but a total replacement of the compacta by cancellous bony supports.

A longitudinal coronal section of the extremity, in the absence of a glass plate reconstruction, brings out the extent and relationship of the varying compacta, (fig.31). The lateral compact layer ceases near the base of the great trochanter, being totally re; :placed by a cancellous system: the upper surface of the neck pres: :ents a small area of compacta for the attachment of the cancellous tissue of the neck: and the medial compacta extends along the under surface of the neck to the margin of the head before its replacement occurs. It is possible then from the distribution of the compacta to determine that on the under side of the neck and medial surface there is the earliest concentration and speediest uniformity of direction of the forces acting along the femur: and that the trochanters take no part in the formation of the weight transmission column.

B. The spongiosa:- The elements of the spongiosa, ar- :ranged on definite mechanical principles, are placed so that they lie in the lines of strongest 'pressure and of strongest tension'. Their resolution into 'mechanical systems of lamellae' is thus generally agreed on, and the description of the arrangement given below/

below differs only in the interpretation of the exact orientation of the various lamellae systems, but even as such requires a preliminary statement as to the mechanical requirements which have been accepted (fig.32.) The essential static problem is the conversion of a force acting downwards at A-B into a force acting along E-F; that is the conversion of a shearing force at the head of the femur into the direct force of the femoral shaft. Mechanically such a conversion is resolved by a duplicate series of curves, respectively concave and convex upwards and intersecting at the axis M-N. The curves which are concave upwards are 'pressure' curves, those convex upwards are 'tension' curves, and in both series the steep end of each curve corresponds to the minimal amount of strain, and the flat end to the maximum. At A-B therefore the strain is zero, at C-D at its maximum.

Fig. 31.

The compacta in longitudinal coronal section.

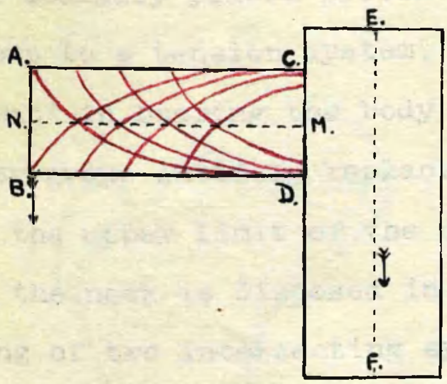


Fig. 32.
To explain the static condition at the proximal end of the femur.

As seen on longitudinal section (fig.33) the proximal end of the femur corresponds very closely with the mechanical condition figured. The cancellous tissue is arranged in series of duplicate intersecting arches, each series in relation to the axis of its/

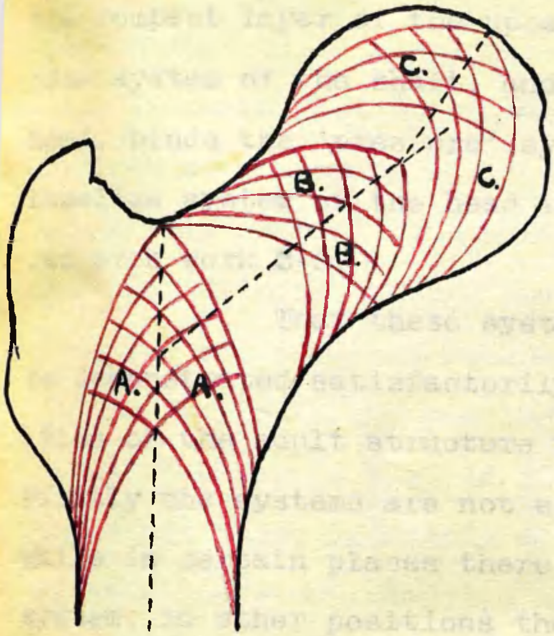


Fig.33.
The mechanical desposition of the spongiosa of the femur.

its particular section of the bone. Thus we propose to describe a lam:
:ellae system of the shaft, a system of the neck, and a system of the head, since the axes of these divi:
:sions are in different planes. The main mechanical column of the shaft consists of the intersecting arch:
:work A-A. This archwork rests on the compact bone of the shaft circum
:ference, and extends downwards to below the lesser trochanter. Central
:ly the fibres intersect in the axis of the shaft, but are continued on:
:wards through the thickness of the column,the apex of which is in the region of the trochanteric fossa. The medially placed fibres belong to a pressure system,and the lateral group to a tension system, tending respectively to be 'flattened'and 'bent' in bearing the body weight: and it will be noted that the lat:
:ter group entirely replaces the compacta of the shaft which ceases at the upper limit of the origin of the system. The lamellae system of the neck is disposed in a similar manner, an archwork B-B,consist:
:ing of two intersecting systems. On the compact bony wall of the medial side of the shaft and under side of the neck there rests a system radiating upwards towards the upper part of the head. This is the main system of the neck, the 'pressure' transmission column between/

between the head and the shaft. The 'tension' system is attached to the compact layer of the upper surface of the neck, and to the lamel: :lae system of the shaft, and passing towards the lower part of the head, binds the 'pressure' system to the column of the shaft. The lamellae system of the head is represented by the similarly construct: :ed arch work C-C.

That these systems are distinct from one another cannot be demonstrated satisfactorily in the adult bone, for in the produc: :tion of the adult structure there are two modifying influences. Firstly the systems are not equally nor uniformly developed. so that while in certain places there is a full retention of the appropriate system, in other positions the arrangement of the cancellous tissue is non-systematic or 'indeterminate'. Secondly there is the development of a seeming continuity between the systems of the different regions into which the bone extremity has been divided. Examination of a young bone, however, (say 10 years) Fig. 34. demonstrates the original fundamental separation of the systems of the head from those of the shaft and neck by the epiphyseal cartilage, and the absence of the epiphysis of the great trochanter sim: :plifies the analysis of the systems of the shaft. In the head the cancellous tissue is disposed mainly as a 'pressure' system, the curves of which are very flat, indicative of the high degree of mechanical function. The intersecting 'tension' group of lamellae is poorly developed, and tends to run to the medial part/

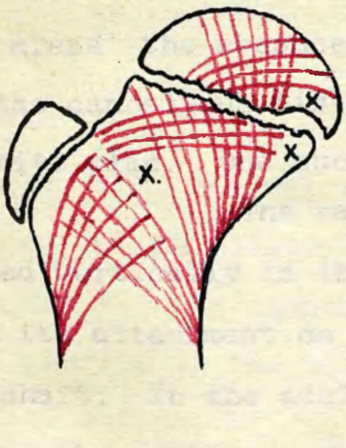


Fig. 34.
The cancellous systems at ten years of age.

part of the head. In the neck the 'pressure' group of fibres pre-dominates; it rests below on a comparatively short length of the neck compacta, but spreads out above practically over the whole breadth of the epiphyseal surface of the neck. The curves are again remarkably flat. Intersecting this 'pressure' system, there is quite a definite, though less massive 'tension' system composed of lamellae of very much steeper curves. The system of the shaft re:tains very much the previously described formation. The 'indeter:minate' areas (x.x.x. in fig.34.) are already well defined. Now in the adult there is simply a further specialization of those systems already differentiated and a development of a seeming continuity be:tween the systems of different parts, so that the interpretation of the classical diagrams of MEYER or WARD is simplified. MEYER'S dia:gram is reproduced in fig. 35, and is self explanatory.

Though described as if they are continuously in the same plane, we would support DICKSON'S contention that on reconstruc:tion the lamellae systems will be found disposed in spirals.

As determinant of the positions of the 'indetermin:ate areas' the absence of definitely directed strain is predominant and the cancellous tissue is therefore not arranged according to any definite plan. One such at Z (fig.35) is known as 'WARD'S triangle'.

The calcar femorale of MERKEL is a shelf of bone placed vertically in the cancellous tissue and projecting laterally from its attachment on the lower part of the neck and upper part of the shaft. In the adult it is about $\frac{5}{8}$ inches in depth, and placed nearer the posterior than the anterior surface of the bone is direct:ed downwards and forwards. In relation to the statics of the bone it forms the postero-medial boundary of the mechanical column and represents/

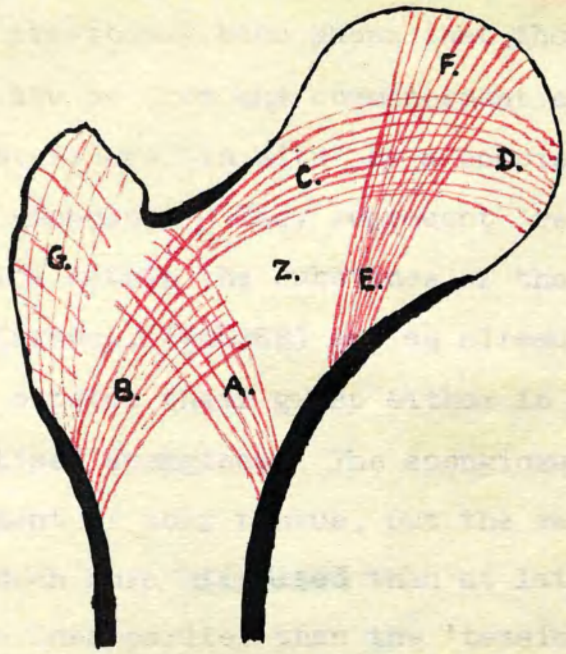


Fig.35.
Internal structure of adult bone. (MEYER.).

A. Pressure system of shaft.
B. Tension system of shaft seemingly continued through C. the tension of the neck to D.the tension system of the head: described by MEYER as a single system.
E. Pressure system of the neck continued to F.the pressure system of the head.
G. Lamellae system of the great trochanter is of fibres parallel to the surface intersected by those at right angles: the latter are by some writers described as in continuity with the pressure system A. of the shaft.

represents the "concentration" of the pressure systems of the neck and shaft in the direct line of the inertial momentum of the trunk on the femur. In regard to its development,cases have been described of its absence in the adult bone, but about the 4th.year we have found indications of the presence of the posterior infolding. The earliest appearance of the anterior calcar was about the 14th-16th. year./

year. It has previously been shown that the calcara are compact bone, and they are so from the commencement of their formation; that is they are not formed "in situ" by a compression together of ele:ments of the spongiosa. They represent "retentions of the compact wall of the neck within the substance of the bone after the growth of the circumference, (SOLGER) and as already indicated there is no static column outside their grasp either in the form of compact layer or of systematised spongiosa. The spongiosa is laid down in the early development of bony tissue, but the reticulum is much more dense though much more diffused than at later periods. The 'pressure' systems are defined earlier than the 'tension' systems.

At some period after the 50th. year the spongiosa may become the seat of a slow progressive reabsorbtion, orteoporosis sen:ile. This condition is a pathological one: it is generalised throughout the whole skeleton, and in such a bone as the femur the "indeterminate" or non systematised cancellous tissue is first af:fected. Thus we have held that these changes are not normal(v.post) and they certainly do not result as the "giving" of the bone due to long sustained mechanical strain. In its progressive course, however, the condition ultimately affects the mechanical systems, and finally even the 'calcara femoralia' in common with the whole cortex, so that there is the liability to fracture of the neck of the femur, through the inability to resolve even normal static conditions. The fracture most commonly occurs at one of two positions, depending en:tirely on the mode of application of the causative strain. If the fracture is due to a fall on the feet, or so that the strain travels through/

through the length of the femur, the fracture is subcapital, at the junction of the head and neck. If the strain, however, is applied in the axis of the neck, such as from a fall on the great trochanter, the fracture occurs at the base of the neck, medial to the capsular attachment in front, lateral to the attachment behind. In this latter group there is a secondary longitudinal fracture of the great trochan:
:ter due to the chisel splitting action of the posterior calcar fem:
:orale on the cancellous tissues of the trochanter (THOMPSON).

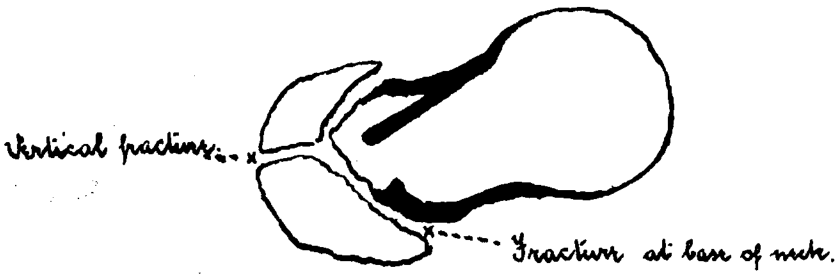


Fig.36.
The secondary fracture of the great trochanter in fracture of the neck. Modified from THOMPSON.

Regarding the position of the limb in fractures of the neck the ex:
:ternal rotation is not due to the anterior direction of the neck of the femur: but is the result of the preponderance of the external ro:
:tators and of the asymetry of the mass distribution of the soft parts round the long axis of the bone, the lateral parts being heavier than the medial.

8./

8. THE GENERAL ANATOMY OF THE ACETABULUM.

The acetabulum, the passive element of the hip joint, is an almost hemispherical cavity into which the head of the femur is received. It consists partly of bone and partly of fibrous and fibro-cartilaginous tissues. The bony part is formed by the fusion of the components of the os innominatum at their most massive portions, and the proportional representation of the ilium is a little less than two-fifths of the whole, and of the ischium a little more than two-fifths. The peripheral part of the bony hemisphere is interrupted in its lower part by the acetabular notch, or partial persistance of an embryonic interval between the pubic and ischial elements; and similar, though less constant and much smaller, interruptions are found between the other components. The bony acetabulum is divisible into two distinct areas, a peripheral articular area, and a central non-articular portion. The articular part of the acetabulum (facies lunata) is a horse shoe shaped surface lining the wall of the hollow and interrupted at the acetabular notch so that it possesses two extremities or 'horns'. Within this articular surface lies the non-articular area, (fossa acetabuli,) depressed below the level of the articular bone and open below into the acetabular notch: in it are lodged a mass of fatty tissue and the lig. teres. The interruption at the acetabular notch is in major part eliminated in the recent state by the transverse ligament of the acetabulum completing the marginal circumference. Attached to the bony rim and to the lateral border of the transverse ligament is the cotyloid ligament, (labrum glenoidale) a ring of fibro-cartilaginous structure.

Into the formation of the acetabulum, therefore, there enter/

enter two structural units. There is a bony part, articular and non-articular, and a fibrous part made up of cotyloid and transverse liga:ments, and the round ligament and Haversian pad of fat. The role of the latter group of structures in the formation of the female articular element of the hip joint will be discussed when dealing with its development and with certain aspects of the articular mech:anism. Primarily, however, it is necessary to describe in some de:tail the essential articular component, the bony acetabulum, and the adult anatomy of the other elements.

A. The osseous acetabulum:- On antero-posterior section the bony acetabulum subtends an angle of 170° to 175°, so that its peripheral rim is placed just minimal to the spherical equator. Its actual size, however, like that of the head of the femur, is almost certainly indicative of the sex of the bone to which it belongs. "In the male the average diameter is 5.2 cms. the smallest being 4.5 cms. and the largest 5.75 cms; in the female the average measurement is 4.6 cms., the range being from 4.3 to 5.2 cms." (DERRY). The size of the acetabulum therefore is not merely relative to the size of the os innominatum as a whole but there exists an absolute difference between the sexes. The position of the acetabulum, its axis, and its curvature form the subjects of succeeding paragraphs, but gener:ally speaking it is placed obliquely so that its axis is directed forwards, outwards and downwards, though in this respect there are individual and probably definite sexual differences. The free margin of the acetabulum is undulating, and is so indicative of its forma:tion: for at the places of fusion of its elements there are reces:sions inwards, (concavitas supercilii acet. HYRTL,) and between these/

these there are excursions outwards of all three bones. The recession between the ilium and the ischium is usually not well marked; that between the ilium and pubis is almost constant; the other between the ischium and the pubic combination is the acetabular notch, which in only a few cases is bridged by bone. The facies lunata, as already indicated, is placed on the most massive portions of the acetabular components and is the peripheral part of the bony cavity. In virtue of its shape it only grasps the femoral head above, behind, and in front, so that in the pendulum movements of the limb this surface is very comparable to the socket of a hinge joint. The broadest part of the articular surface is on the ilial portion, the acetabular roof, and on an average measures 2.5 cms.; it narrows posteriorly, though there is a broadening out on the middle of the ischium; it is smallest on the pubic element, being scarcely 1.25 cms. broad. Examination of the boundaries of this surface shows that they do not pursue a circular course but that they are parts of a spiral curve. This is most evident if the posterior border is placed in a perpendicular plane, (FICK) when on the right side the anterior continuation will be found to commence a right winding spiral, and to wind to the left on the left side. (fig.37).

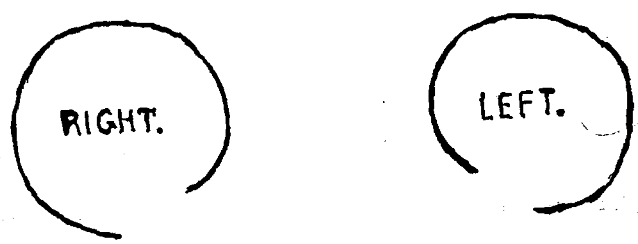


Fig. 37.
The curve of the lateral border of the acetabulum. (after FICK.)

The articular cartilage covering the facies lunata, in com:mon with all concave joint surfaces, increases in thickness from the central towards the peripheral border, being from .5 to .9 m.m. inter:nally and from .8 m.m.to 3 m.m. externally. The greatest thickness is placed supero-posteriorly, while anteriorly and inferiorly the car:tilage is thinnest. It is therefore deduced that the upper and pos:terior parts of the sickle have a greater femoral pressure applied to them,than the anterior and inferior parts, a fact in exact agree:ment with the deduction made from a study of the head of the femur. As will be shown later the antero-inferior parts are only subject to pressure in maximal extension of the limb. It is often possible to recognise the position of union of the acetabular elements by a linear decrease in the amount of cartilage, indicated by the presence of a grey line. As a further stage of this decrease of cartilage, the an:terior end of the cartilaginous sickle is not uncommonly separated off by a cartilage-free groove, the isolated cartilage being circular:ly shaped and co-extensive with the pubic area.

In the middle of the acetabulum surrounded by the articular sickle but continued below into the acetabular notch is the fossa acetabuli. It is uncovered by articular cartilage and so is not reckoned as part of the articular surface: it is not concerned in the transmission of femoral force,nor is it correct to state that the fossa is the groove for the lig.teres. It should rather be regarded as an elimination of articular surface unnecessary in the mechanism of the joint and comparable to the transverse line of the ulna in the elbow joint. It is depressed below the level of the articular por:tion - about 3 to 4 m.m.,- but this is equalized in the recent state by its contents, the round ligament and the articular pad of fat.

The/

The fossa is covered by a thin easily detached periostium, superficial to which is the very lax fatty tissue (Haversian gland).

B. The transverse ligament:- This structure consists of three parts, one being the continuation of the cotyloid ligament. The second passes between the anterior and posterior 'horns' of the ar: :ticular acetabulum and is directed towards the interior of the cavity: it is formed purely of fibrous tissue, cartilage cells being entirely absent. External to this is the third part running as obliquely plac: :ed fibres between the margins of the notch and extending even to the upper posterior angle of the obturator foramen. The whole ligament is occasionally ossified. Below the ligament there is an interval of which mention has already been made in reference to the passage of vessels within the acetabulum. The length of the ligament is about 3 cms., its breadth about 1 cm.

C. The cotyloid ligament:- The cotyloid ligament is a fibro-cartilaginous ring which not only 'levels up' the slight notches in the bony margin but bridges over the acetabular notch: very often, however, one or other of the other rim depressions is also bridged over by the ligament so that a groove remains between the ligament and the bone. POIRIER has described such a slit under the whole upper part of the ligament. On transverse section the cotyloid ligament is a 3-angled prism with 3 surfaces: the attached surface or base:

The outer surface, slightly convex, at parts fused with the capsule:

the inner surface, smooth and concave, lying closely on the head of the femur, and following the curvature of the acet: :abulum.

The ligament consists of fibro-cartilage only towards its base, the free/

free border being composed solely of fibrous tissue, the individual fibres of which spread obliquely into the ligament from the bony margin, and then complete a more or less circular caurse. It is almost always possible, however, to find on the femoral surface, superficially, isolated completely circular fibres, but the usual description that the ligament consists entirely of such fibres is not correct. HENLE has described on the femoral surface radially running fibres which may be traced on to the cartilage of the articular surface as far as its medial border, giving a direct suggestion to the idea of continuity between the two articular surfaces. Morphologically we consider the ligament as unossified bone rather than as variously modified synovial membrane, KEITH; and the incidence of its modifications is related to the underlying causation of its non-ossification.

The base of the ligament, attached to the bony rim, is placed at the equator of the acetabular sphere but continuing as it does the spherical curvature the free sharp border of the ligament is placed on a curve of **smaller** radius than that of the acetabulum. The marginal radius (in the male) is 2.4 cms., that is less than the radius of the acetabulum or the radius of the head of the femur: the depth of the complete acetabulum is 3.3 cms., that is greater than

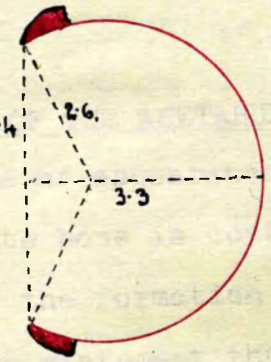


Fig. 38.
The average measurements of the acetabulum in the male.

the/

the radius of the acetabulum, so that all sections through the centre and inclusive of the ligament are arcs subtending angles greater than 180°. In order that lateral movement of the head of the femur may occur in the mechanism of the joint that part of the spherical wall maximal to 180° and of diameter less than the femoral head must remain of extensile structure, and as such is the cotyloid ligament. This ligament is present, then, not to deepen the acetabular socket but to diminish its osseous extent. FICK has drawn attention to those cases in which the ligament is completely ossified, and states that the head of the femur would not then be capable of lateral movement: in two specimens of this condition which we have examined the femorale head was capable of and did undergo, on flexion of the limb, appreciable lateral movement, since the ossified ligament did not continue the spherical curve of the acetabulum but was of radius of equal extent to the bony socket. In function the ligament is so closely applied to the head of the femur in all positions of the limb, though in certain inclusion of the femoral synovial pads must be allowed, that the joint cavity is "hermetically sealed" even to the passage of synovia, a con:
:dition previously shown to be necessary to the action of an organised articulation.

9. THE MORPHOLOGY OF THE ACETABULUM.

Up to the time of appearance of the "joint cleft" the "anlage" of the innominate bone is continuous with that of the femur. With the histogenesis of the formation of the cleft we are not at pres:
:ent concerned beyond the statement that we do not consider there is evidence/

evidence of an extra-capsular mesoblastic immigration; but rather that the change of cell type which is incident to its appearance is local, and is concerned in the definition of the articular surfaces before the formation of the cleft.(1) In embryos 2.5 and .3.cms. long, (50 and 57 days MALL formula) the primative acetabulum is well formed, and though differing in certain respects from the adult structure it is impossible to agree with LOCKWOOD "that there is not at first a pelvic socket in which the head of the femur lies". There is a well developed socket at these periods, which though not wholly coincident as chondral tissue with that of the head of the femur is at least co-terminous and proportionate in depth as an articular surface in its earliest appearance. The early acetabulum is formed by the ilium and ischium but the pubis is prevented contiguity with the head of the femur by an intervening mass of undifferentiated mesoblast and does not therefore take part in the boundary wall of the primary sock:
:et. (In comparative anatomy the pubis is found to be very variable in its development, so that while in some animals it forms part of the acetabulum - though always the smallest part, - in others it does not reach the ilium and so is excluded from that cavity). Relative to the mesoblast, which in human ontogeny excludes the pubis from the acetabulum, the joint cleft developes in two directions: upwards on its femoral surface and downwards through its centre, so that there is formed the lig. teres as part of the early or primative capsule and continuous medial to the lower part of the central cleft with the marginal capsule.(vide ante). On the acetabular surface of the ligament/

1. PETERSEN and VON FRIELANDER have shown that the shape of the articular surface is defined before the cleft is formed.

ligament the remaining mesoblast spreads forwards over the pubis and vascularises in common with the chondral tissue of that element. De: :fining the primative acetabulum as that area of the innominate bone within which the joint cleft is bounded and to whose margins the primative capsule is attached, it is possible to recognise after re- :construction local modifications in the pre-chondrium in the posi: :tions of the future cotyloid and transverse ligaments and as defects between the elements on either side of the pubis, that between the ischium and pubis being of considerable extent and with the ilio- pubic linear mesoblastic retention completely isolating the chondral pubis from the chondral tissue of ischium and ilium: and these modi: :fications are articular in the sense that they are in contact with the head of the femur. In regard to the cotyloid ligament it is de: :fined best over the ischial and ilial margins, and in all situations is present as a gradual transition from the chondral to the fibrous texture there being no boundary between the basal cartilage and the marginal fibrous tissue. Similar facts are found in the structure of the primative transverse ligament, there is no demarcation between the cartilage cells of its lateral attachments and the fibrous ele: :ments of its central parts. Superficially adherent to both liga- :ments is the continuously fibrous and easily differentiated prima- :tive capsule. These ligamentous elements, then, are modified parts of the articular acetabulum and are morphological derivatives of the innominate bone (fig.39.) Regarding the separation of the pubic cartilage from the combined ilio-ischial mass, so far this has been demonstrated only in the human subject, (ROSENBERG): in other/

other mammalia the ossifications of the four pelvic bone elements

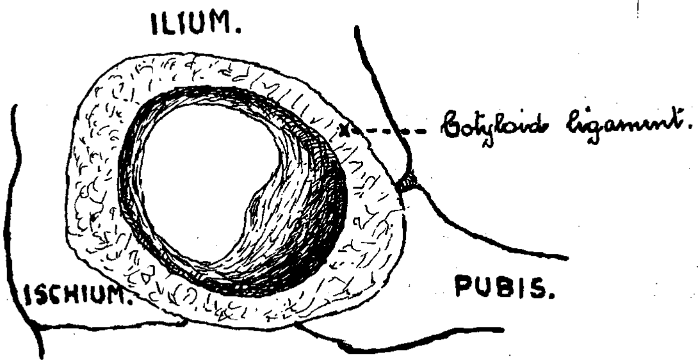


Fig. 39.
A reconstruction of the acetabulum of a 3.cm. embryo.

are described as occurring in a single cartige 'anlage' (BRONN). The fourth component of the os innominatum, the os acetabuli, now recog::nised as a definite element in all mammalian orders except mono::tremes, takes part in the formation of the acetabulum in a greater number of animals than was indicated in its earliest description by GEGENBAUER. This author described in Macacus that the pubis was ex::cluded from the acetabular wall by a "calcified cartilage", and subsequently detected the appearance of a similar element in Lepus and Cynocephalus: KRAUSE after more extended observation has indic::ated the true osseous nature of the os acetabuli, and gave the fol::lowing description. It lies anterior to the acetabular notch but its existence as a separate element, though differing in different species, is of very short duration. It may fuse primarily with any of the other elements, but most seldom with the pubis: if it does fuse with the pubis it forms that part of the acetabulum which would/

would be taken by that element. In its highest degree of development it is the same thickness as the other bones so that it appears on both surfaces of the pelvis, but more commonly it is a superficial lamellae and does not intervene medially between the ilium and the ischium. It is a definite pelvic element and not an epiphysis: for it has homologies throughout all the mammalia and it fuses, not with a definite bone, but with any of the other pelvic components even though it is laid down much later than the other elements and its ossification is not begun when the others have assumed their defin:
:ite osseous form.

In a foetus of 4 months the defect between the carti:
:lages of the ischium and pubis is partially obliterated by the for:
:ward extra-articular growth of the ischium to form the floor of the acetabular fossa. At this period and up to the 6th. - 7th. month the acetabulum is proportionate in its depth to the size of the head of the femur, though at no stage so far is the cavity more than hemispherical in a section through its axis. From this period onwards til the 3rd. - 4th. years the cavity is proportionately smaller than the femoral head, which is therefore grasped in a less perfect manner than at later periods of full function: but we cannot agree with VON AMMON that " the socket is a shallow saucer shaped depression". It has not diminished from its hemispheric:
:al extent. At three years of age the three main components of the acetabulum have converged in ossification to form the acet:
:abulum but are still separated by intervening cartilage, which is thus/

thus tri-radiate. In this cartilage about twelve years additional centres of ossification appear, and as a general rule join with the boundary bones. One of these ossicles forms the independent os acetabuli which subsequently fuses with and constitutes the acetabul: :ar part of the pubis, or more rarely may remain separate. At sixteen years the ossification of the acetabulum is usually complete.

Congenital dislocation of the hip is a loss of the primary contact between the femoral head and the acetabulum, not traumatic or the result of disease but as a malformation due to the loss of joint stability. The condition is described as occurring in the foetus, at birth, or after birth, but the majority of writers are agreed that it takes place in early infancy, and that the pre- :disposing factor is an imperfect socket while the rational move- :ments of the limb in flexion and extension form the exciting cause. (FRÖLICK, VÖGEL, TUBBY, BADE, THOMPSON, etc.) The anatomical changes which have been indicated as usually present are, that the neck of the femur is anteverted, shortened and depressed; that the lig. teres is present intact but modified in that there is a great increase of its length; and that the acetabulum is small and flat. It is necessary, however, to distinguish whether these changes are really those of the original malformation or whether they are not entirely secondary to the use of the malformed parts. We have already considered the femoral abnormalities and indicated their secondary nature. In regard to the lengthening of the ligamentum teres/

teres we would hold that this justifies the conclusion that the dis: :location has been of gradual onset: for we have shown that the head of the femur may not at any period be displaced from its socket without a rupture of that band. The acetabulum is most often in- :dicated as the structure developmentally at fault, but we would be- :lieve this also a secondary change: for it is well known that the opposing joint surfaces depend on the contact established between them for their conformation or 'moulding'; and the absence of this contact would be sufficient to account for any marked shallowness of the cavity. We would put forward the following view as a con: :tribution to the etiology of the condition. The surfaces of the hip joint are in maximal contact in extension and abduction of the limb but minimally so in the foetal position of flexion and adduction, (so that at birth the acetabulum is not proportionate in its depth to the size of the femoral head;) and in the absence of that factor which was the main element in the establishment and retention of joint contact, that is muscular tonus, the separated surfaces will not assume apposition but will be relatively and gradually further displaced on the application of the body weight on the lower limbs in crawling and walking.

B. THE PHYSICAL ANATOMY OF THE FEMUR AND ACETABULUM.

1. THE NECK OF THE FEMUR AS A STATIC PROBLEM.

The angulation of the limbs is a beneficial structural adaptation to the mechanical requirements, and in connection with the proximal component of the weight transmitting couple of which each limb consists, the two points of paramount importance, so far as the preservation of stability in the sense of forming an efficient mech: :anical support is concerned, are the length of the component and its degree of angulation to the distal element.

A. The length of the neck:-

The purposive necessity of the essentially human character: :istic of the comparatively great length of the neck of the femur has been assigned to various functional causes, most of which are open to the objection of being simply statements of fact of the existing con: :ditions and not explanations of those really associated circumstances. For example, it is not necessary to lengthen the femoral neck in or- :der to obtain a greater amount of adductor muscle; rather it should be said that, the neck of the femur being lengthened, a greater amount of adductor muscle will become an absolute necessity. The length of the neck of the femur is really proportional to the breadth of the pelvis.

With the increase of the pelvic transverse diameter in relation to the pelvic antero-posterior diameter(1) there has been a

1. Topinard, Anthropology p.305.
Duckworth, Anthropology p.295. shows this by means of an index (modified from Topinard,) where when the transverse diameter is 100, the ant.-post. diameter is as follows:-

Edentata...138	Lemuroidia...144
Rodentia...133	Cebidae 135
Carnivora..132	Chimpanzee... 97
Ungulata...123	Gorilla..... 79

Homidae..73. (Turner, Chall. Rept., average of white races.)

a concomitant increase in the divergence of the lines of weight pro:
:pagation from the vertebral column to the lower limbs. For, when the antero-posterior measurements are more carefully analysed, it will be found that the reduction is purely of the post-acetabular part of those measurements: the pre-acetabular, on the other hand, undergoes a relative increase concomitant with the increase of the transverse diameter. (figs.40 and 41.) In Table 2.the measurements carried out and the methods of comparison adopted are explained, showing this re-
:lationship of the various pelvic measurements to one another. While not seeking to dissociate the final correlation of the causative fac:
:tor in man from the assumption of the erect position, yet it may be

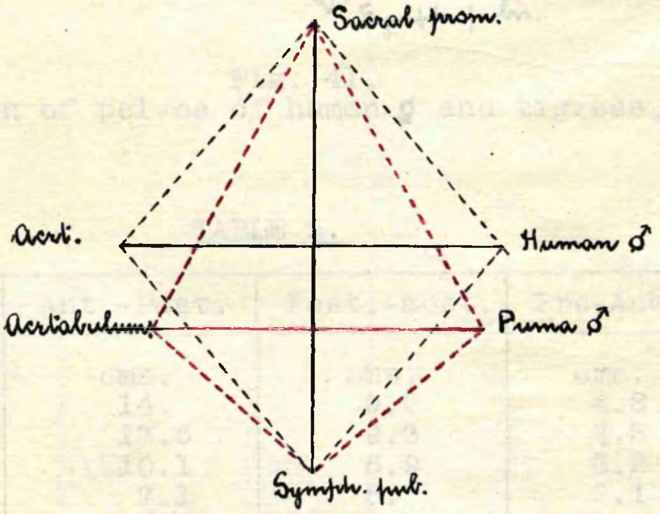


Fig.40.
The pelvis of a human ♂ has been drawn to a definite scale, and drawn to the same scale the pelvis of a ♂ puma has been superimposed. Note the amount of divergence of the cotylo-sacral lines depends on the position of the inter-acetabular diameter.

stated for the purposes of the present thesis, that with the increase in the transverse towards and greater than the antero-posterior pel:
:vic/

pelvic diameter there is a greater divergence of the lines of weight propagation from the vertebral column to the acetabula, and on this factor it is proposed that the length of the femoral neck is in direct ratio with the relative distance between the acetabula.

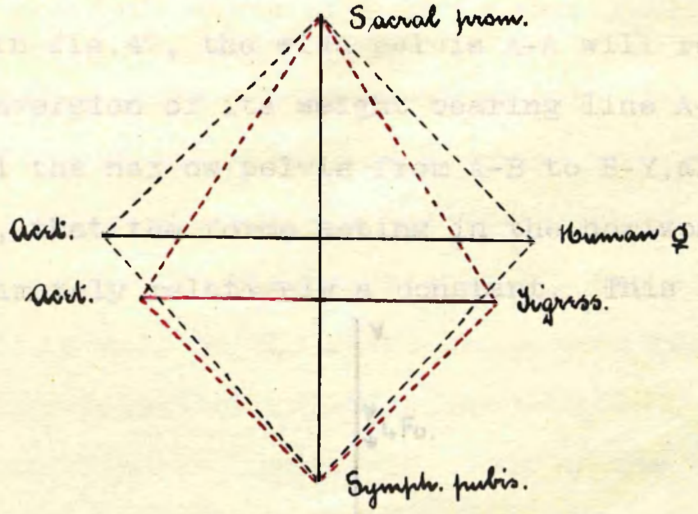


Fig. 41.
Comparison of pelves of human ♀ and tigress, as in fig. 40.

TABLE 2.

	Ant.-Post.	Post.-acet.	Pre-Acet.	Trans.	Index.
	cms.	cms.	cms.	cms.	
Ass. . .	14.	9.2	4.8	10.4	134
Deer . .	13.6	9.3	4.3	8.6	158
Sheep. .	10.1	6.9	3.2	6.7	151
Deer . .	7.1	5.	2.1	4.4	161
Tigress.	9.7	5.7	4	7.2	134
Puma	6.5	4.2	2.3	4.3	151
Cat . .	3.5	2.2	1.3	2.7	130
Gazelle.	6.2	3.9	2.3	4.7	132
Goat	6.2	4.1	2.1	4.2	147
Human F.	11.	5.8	5.2	11.5	95.

(Note:- The apes are excluded from this Table.)

Explanation.- The antero-posterior diameter was measured in the usual way; the transverse is taken as the distance between the centre points of the acetabula on the pelvic aspect, which not being the greatest diameter makes the indices given higher than those usually stated. The post-acetabular length is that part of the antero-posterior diameter which lies posterior to the transverse measurement, the pre-acetabular that part which lies in front. The pelvic index is calculated as usual.

This difference of degree to the horizontal of the pelvic weight bearing lines of pelves of differing widths will mean a differ:
:ence in the amount of resolution necessary to convert this oblique force into the required vertical from the acetabula to the ground: for, as is shown in fig.42, the wide pelvis A-A will require a greater amount of conversion of its weight bearing line A-A into the vertical A-X than will the narrow pelvis from A-B to B-Y, always considering, as is here done, that the force acting in the horizontal plane is in all cases approximately relatively a constant. This is still more evident

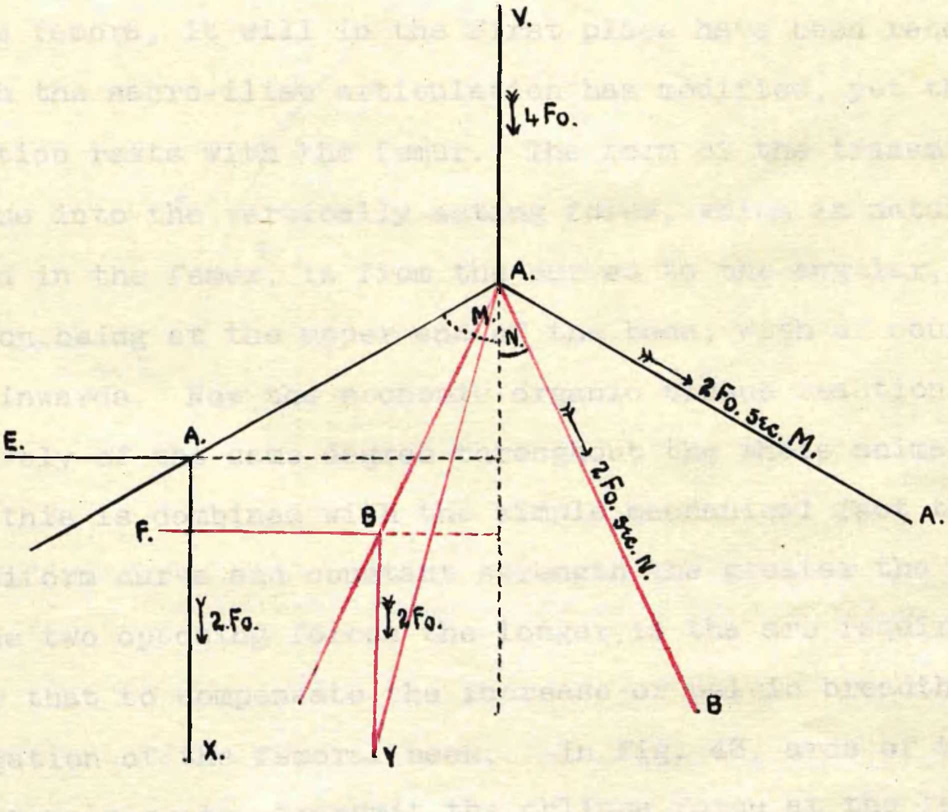


Fig.42.
To show that the amount of divergence of the pelvic weight trans:
:mission lines influences the resolution of the oblique pelvic force into the vertical limb force.

Force/

On fig. 42,

Force acting along VA = 4 Fo.
∴ " " " AA = 2 Fo. Sec.M.
" " " AB = 2 Fo. Sec.N.
" " " AE = 2 Fo. tan.M.
" " " BF = 2 Fo. tan N.

But N < M < 90°.
∴ tan M > tan N.
i.e. force acting along AE > force acting along BF.

if the two lines A-A and A-B be resolved into their component forces, one of which is vertical, when, as is shown in fig.42, a greater amount of pure horizontal force must in the wider pelvis be converted into pure vertical force. In the translation of the effects of this factor to the femora, it will in the first place have been recognised that, though the sacro-iliac articulation has modified, yet the greater modi:fication rests with the femur. The form of the transmission of this oblique into the vertically acting force, which in nature has been ad:opted in the femur, is from the curved to the angular, the curved portion being at the upper end of the bone, with of course the concav:ity inwards. Now the economic organic tissue reaction is a factor re:latively of the same degree throughout the whole animal series: and when this is combined with the simple mechanical fact that in a support of uniform curve and constant strength the greater the approximation of the two opposing forces the longer is the arc required, it will be clear that to compensate the increase of pelvic breadth there must a elongation of the femoral neck. In fig. 43. arcs of the same radius have been made to transmit the oblique force at the femoral head in a curve from the head to the vertical: and as forces acting along a curve act tangentially to that curve, it is shown graphically that the distance from the femoral head to the point where the force acting tangentially on the curve is purely vertical is in the wider pelvis

a/

a longer distance than in the narrow pelvis. Thus, taking the

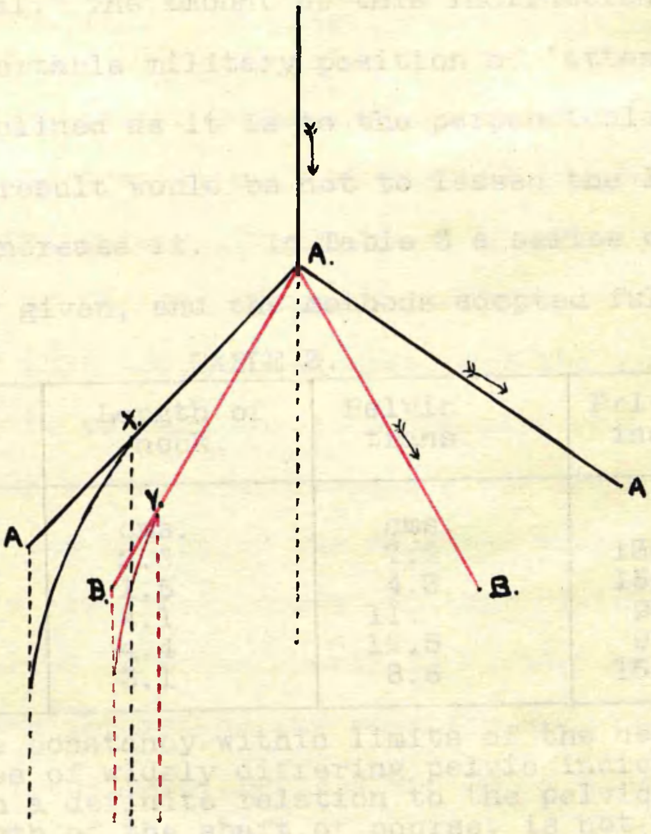


Fig.43.
The transmission of the oblique pelvic force by means of a curve to the perpendicular. The arcs at A and B are of equal radii.

"mechanical axis" of the lower limb - that is, the line of weight transmission, which, joining the center of the head with the centre of the knee, passes, when prolonged, through the centre of the ankle joint - taking this as a vertical constant throughout the whole mamma:
:lian series, the greater the divergence of the lines of weight pro:
:pagation of the pelvis, that is, the greater the ratio of the pelvic transverse to the post-acetabular part of the antero-posterior meas-
:urement/

measurement the longer will the neck of the femur require to be.(1) It may be objected that the mechanical axis of the lower limb is not, in the human subject at least, a vertical quantity, but is inclined to the vertical. The amount of this inclination is small, exists only in the uncomfortable military position of 'attention' to the extent of 3°,(2) and inclined as it is to the perpendicular rather than away from it, the result would be not to lessen the length of the neck, but actually to increase it. In Table 3 a series of measurements on this point is given, and the methods adopted fully explained.

TABLE 3.

	Length of neck.	Pelvic trans.	Pelvic index.	N.- T. index.
	cms.	cms.		
Tigress	2.6	7.2	134	36
Puma	1.5	4.3	151	37
Human M.	4.1	11.	95	37
Human F.	4.4	12.5	94	36
Deer	3.1	8.6	158	36

Note the constancy within limits of the neck-transverse indices of pelves of widely differing pelvic indices. Though the neck has such a definite relation to the pelvic transverse width, the length of the shaft, of course, is not proportional to the length of the neck.

Explanation. The length of the neck was taken as the distance from the point of intersection of the axes of the shaft and of the neck to the "base line" of the head, in the axis of the neck. The axis of the shaft is taken as that line which, extending through the centre of the bone, if prolonged downwards would bisect the intercondylar line at the lower and of the femur. The axis of the neck is that line lying in the centre of the neck which bisects, though not at right angles, the "base line" of the head. This base line of the head joins the margin of the articular cartilage at the highest point on the neck with the margin at the lowest point, these being the two most/

1. Under investigation at the present time by the writer is the question of the reduction of the length of the neck of the human humerus as compared with the neck of the lower forms.
2. Fick. Handb. d. Anat. u. Mech. d. Gelenke, Bd. 3.s.525

most fixed points obtainable.[1] A. Tracings of each bone examined were made from the anterior aspect by means of the dioptograph, andthe measurements obtained from the projected diagram which was always of the same dimensions as the original bone. This method was adopted in preference to any other on account of being the one of smallest possible error, no external measurement being found which was in the least degree accurate. The neck-transverse index (N-T index) is cal: :culated thus:- $\frac{\text{Length of neck}}{\text{Pelvic trans.}} \times 100$.

Even in the human subject there is evidence of the great: :er length of the femoral neck of the broader pelvis of the female as compared with the male. Cruvielhier, Hyrtl, and others are all agreed on this point: and though Bertaux found the neck of the female femur was less than that of the male, and the right neck shorter than that of the left, yet his absolute accuracy may be doubted, as it is evident from the actual measurements given that some external method of determining the length of the neck was adopted. Sue found the femoral neck "a few lines longer" in the female than in the male. In the present series of bones examined, fifteen male and fifteen female, (Table 4.), notwithstanding the relative shortness of the female femur, it was found that the neck was on an average 3 m.m. longer than in the male: but individually an enormous variation is present, which variation does not coincide with the length of the femur nor with the angle between the neck and the shaft.

TABLE/

1. This does not correspond with what is termed by Hoffa the base line, for his limitation is "that line parallel to the acetabular outlet which passes through the base of the car: :tilage of the Head".

TABLE 4.

Measurement of human femora.

	Length of femur.	Neck	Angle.
	cms.	cms.	o.
1.F.	38.9	4.5	129
2.M.	42.8	4.2	120
3.M.	40.7	3.3	118
4.F.	43.4	4.9	126
5.M.	45.4	4.2	129
6.F.	44.5	4.3	140
7.M.	45.7	4.3	124
8.F.	45.2	4.7	136
9.M.	44.1	2.9	123
10.M.	47.1	4.5	123
11.M.	46.8	3.9	120
12.F.	39.7	4.5	120
13.F.	41.	4.7	116
14.F.	44.3	4.9	142
15.F.	40.	3.9	128
16.M.	44.7	3.4	126
17.F.	44.5	4.3	137
18.F.	45.3	5.1	130
19.F.	40.7	4.2	119
20.M.	45.6	4.6	122
21.M.	43.7	4.7	126
22.M.	47.6	4.9	135
23.M.	45.6	4.	132
24.M.	43.8	4.	137
25.M.	46.7	4.2	113
26.M.	43.2	3.8	123
27.F.	37.6	4.	124
28.F.	41.4	4.3	125
29.F.	43.9	4.	122
30.F.	41.1	3.5	120

Average length of male femur.........cms. 44.2
" " " female " .... " 42.1

Average length of male neck..........cms. 4.1
" " " female "......... " 4.4

Average male angle......125°
" female " ......127°.

<u>Explanation</u> . The length of the neck was obtained as given under Table 3, while the angle is taken as between the axis of the neck and the axis of the shaft. The length of the femur is taken as "the mechanical length" that is, the condyles are placed on a transverse plane and the measurement taken to the head: this, of course, is not the greatest femiral length. Hepburn's osteometric board was used.

In tracing the developmental changes in the length of the neck of the femur in the human subject, it is well known that the human foetus is simian in this respect,- that is, the neck relatively to the adult condition is ill developed. On examination of the pelvis at this foetal stage it has been shown by THOMPSON (1) that sexual charac:teristics are already present at the fourth month, and according to DUCKWORTH (2) the pelvic indices are, for the female 82.4, and for the male 83.6 at this period. Thus associated with a simian pelvis is a simian femur. There is, however, another factor to be consider:ed as causative. As well as the mechanical force there is another force,- a developmental one,- found to be a determining factor in the production of the form, length, etc., of the osseous skeleton. But with a normal relationship between the mechanical forces and the developmental forces the former will serve as a guiding stimulus where:by the latter may most effectively execute the necessary modifica:tions in the different parts of the osseous framework. The converse of this relationship is also true, that whenever there is a disturbance of this relationship there will be anomly of form. The disturbance may be in either of two directions, in both cases passing towards complete suppression: for the mechanical may be diminished or sup:presses with the non-control of, or absence of stimulus to, the de:velopmental, a condition leading towards anomalies of form which will be of the embryonic or the primative type. Or, on the other hand, there may be preponderance, complete or partial, of the mech:anical over the developmental forces, where the anomalies would tend to be progressive, and emphasised at the points of greatest strain./

1. Thompson, Jour. Anat. and Phys. Vol. 23. p. 59.
2. Duckworth, Anthropology, p. 296.

strain. As regards the application of the former, to the lower limbs, it would in the adult be found only in such conditions where from ab:normal causes the femur has not been required to transmit the weight of the body,- for example, in an early complete paralysis, in an early amputation, in extreme hydro-cephalus, etc. In the foetus the devel:opmental force will be in preponderance over the mechanical: that is, the absence of the weight transmission of the body will connotate an absence of those mechanical factors producing the changes which are so typical in the growing human subject,- an increase of the length of the neck of the femur. Thus the absence of the correlation between the mechanical and the developmental forces in the direction of the suppression of the mechanical will in itself constitute a reason as to the shortness of the neck of the foetal femur. In Table 5 there is a tabulation of the measurements of the neck at different ages, showing the relatively great increase once the mechanical strain is brought to bear on the tissues of the neck.

TABLE 5.

Age	Length of neck.	Length of femur.	N.F.Index.
	cms. (av)	cms. (av.)	
Adult F.........	4.4	42.1.	10.2
" M.........	4.1	44.2	9.7
years.18........	4.2	44.4	9.6
" 16........	3.9	40.6	9.6
" 14........	3.5	37.6	9.2
" 10........	2.7	34.4	7.8
" 8........	1.7	25.2	6.7
" 5........	1.1	17.2	6.4
" 4........	.9	14.7	6.1
" 2........	.6	11.6	5.2
At birth........	(.4?)	9.4	4.3
Foetus 5 months.	(.2?)	4.3	4.6

Explanation: All the measurements were carried out as before. The neck-femur index (N.-F.index) cannot be held as of much value apart from the purposes of comparison. It is taken thus:

$$\frac{\text{Length of neck}}{\text{Length of Femur}} \times 100.$$

It will be noted from the table that there is a steady increase in the relative length of the neck up to the age of 12-14 years, at which period the neck of the femur may be said to have reached its maximum ontogenetic length, in the relative sense. Thus it must be evident that to have any appreciable effect on the length of the neck of the femur in the direction of non-elongation the mechanical forces must have been absent from a comparatively early period, though this is presupposing that retrogression cannot take place. I have been able to examine two skeletons in this respect. In skeleton 1 there has been hip joint disease from an early period, so that the left leg is over all 12 cms. shorter than the right. (fig.44.) In comparing the upper ends of the femora, it is more than interesting to note the relatively short neck and the relatively large angle of the diseased side (fig.45.) Absolute measurements were not possible but those given are at least approximate.

Fig.44.

Fig.45.

	Length of Femur	Neck	Angle.
	cms.	cms.	o.
Healthy limb	34.7	3.1	125
Diseased limb.	27.5	1.9	140

In skeleton 2 the first glance at the femora is suf icient to indicate that they could not possibly have borne the weight of the body, and here again the neck of the femur and the angle are of the embryonic type. (figs.46. and 47.)

Fig. 46.

Fig.47.

The approximate measurements are:-

	Length of Femur.	Neck	Angle
	cms.	cms.	o.
Right limb	33.9	(2.0?)	(140?)
Left limb.	35.1	2.1	135

The other possibility - that is, where there is a pre-:ponderance of the mechanical over the developmental forces - is il::lustrated in the condition of rachitis. Here, from pathological causes/

causes, the developmental forces cannot take their proper place in the production of the form of the bone. Thus apart from an asso: :ciation with an increase absolute and relative of the pelvic trans: :verse diameter, the rachitis femur undergoes, concomitant with the increase of its anterior curve a curving outwards of its upper part, or in other cases a curving inwards of its lower part, more commonly the former. That is, as is shown in figs. 48. and 49. the femoral neck, the curved weight transmitting line from the head to the verti: :cal, has spread far past its normal limit, and may here be said,

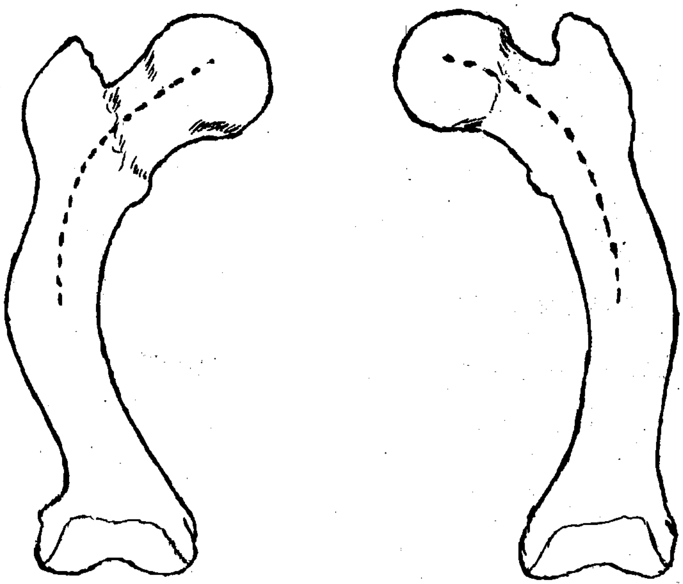


Fig.48.
Rachitic femora.

Fig.49
Physiological elongation of the neck.

physiologically rather than anatomically of course, to extend from the head past the middle of the shaft

It may be objected that no account has been taken of another/

another acting force, the muscular force or muscular pull, which by many authors is spoken of as moulding the whole osseous skeleton. Muscular force is, however, a modifying rather than a controlling factor, and will never under normal conditions actin a manner to con:trol or divert the action of the mechanical force. Muscular force is thus simply the dynamic expression of those factors which under normal conditions, that is, with a normally acting mechanical force,- temporarily rather than permanently bring about and sustain in the new direction of the line of force, modifications of the direction of the normal line of action of the mechanical force. Through the continued action in one constant direction it may be that a local modification of form, contour, size,etc. will be produced, but never will a normal muscular force control or divert the normal mechanical force. This expression of the influence of muscular force does not in the least detract from what is known as "Wolff's law", wherein it is held "that the shape of the bones is determined by the condi:tions of reaction to body weight, and the stress and strain of muscular action".

The great length of the neck of the femur in the human sub:ject is, then, an adaptation to the increased width of the pelvis. The structural axes of body support are thus removed from the line of body gravity to the maximum extent, to compensate for which there must be the maximum of the movements of adduction and abduction at the hip joints to allow of the ossilation of the gravity line of the trunk towards the unit of support in biped progression.

B. The angle of inclination of the neck:- The angle of the neck of the femur, often referred to as "the angle of inclination", is here understood as the medially open angle between the axis of the neck and the axis of the shaft. According to the generally accepted yet some: :what diverse statements of different authors, this angle varies throughout the mammalian series and in man it varies with the age and with the sex. The conclusions of HUMPHRY in regard to this point, those which have become classic, are:-

1. The angle varies at any given age.
2. It is smaller in short bones than in long: most likely to be small when the pelvis is wide: the combination of these two usually rendering it smaller in women than in men.
3. It decreases during the period of growth, but after growth is completed there is no change.
4. If the limb be relieved of its weight during growth the angle remains open, or may become wider.

Deductions such as these could not be improved on as bases on which to institute an inquiry into this question - the amount of divergence between the axes of the two components of the femur.

In his second conclusion HUMPHRY states that "the angle of the neck of the femur is most likely to be small when the pel: :vis is wide." From this it would of necessity follow that the angle is most likely to be great when the pelvis is narrow. That the angle looks as if it would be smaller in the wider pelvis, onw would at a first glance deduce from fig. 43. If,however, these diagrams are read, as/

as they are drawn, in the truly mechanical sense, it will be seen that this cannot possibly be the case, and especially if a resolution is made as in fig.50. Where, if in the two pelves A - B and A - C the respective lengths of the necks of the femora be B - X and C - Y, or

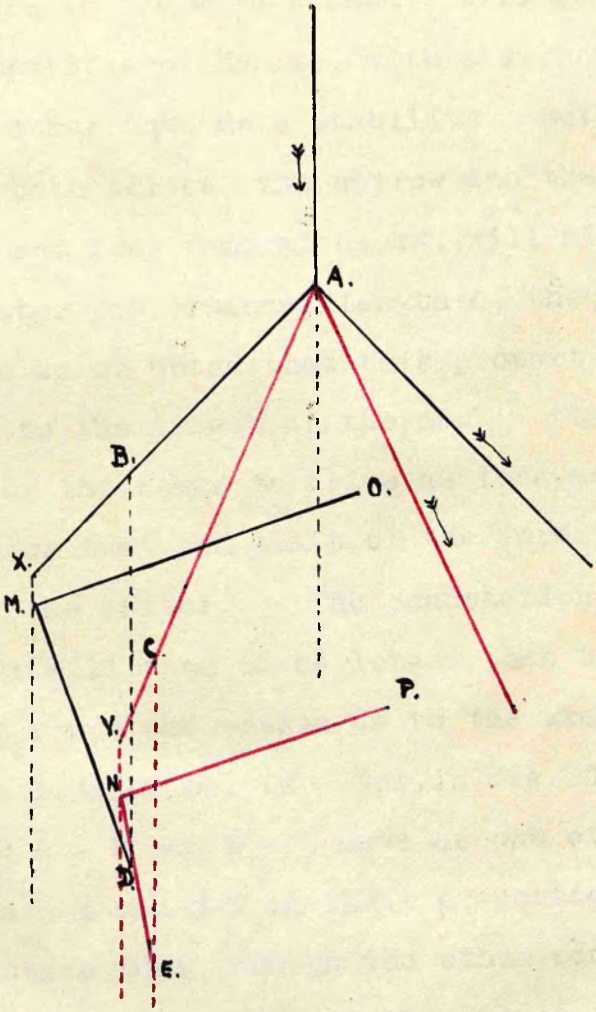


Fig.50.
To show that the angle of the neck of the femur tends to remain a constant. (see text).

some lines running between the verticals at B and X and C and Y, with, of course, the neck of greater length in the wider pelvis, then it is obvious that the inclination of the shaft from the extremity of the neck back to the vertical at the knee will always vary according to the/

the length given to the shaft. Now the deviation from the vertical of the shaft, and in consequence its length, will not be determined by purely mechanical causes, but these will be influenced by other factors, developmental and physiological in the main: yet the less deviation there is the more economic will be the organisation requir: :ed, made compatible of course, with a structure which is convenient for purposes other than mere stability. But the application of the same laws to both pelves, the narrow and the wide, with their respect: :ively short and long femoral necks, will always result in the tenden: :cy to a greater proportional length of the femur of the latter pel- :vis. It is to be noted that this proportional length is not in direct ratio to the length of the neck: for example, in one species if the neck of the femur be twice as long as in a second species, it does not follow that the shaft of the former femur will be twice as the shaft of the latter. The connotation is only that the shaft of the former will tend to be longer than the shaft of the latter. On this fact rests the reason as to the greater inclination of the femur of the broader pelvis Now, in fig.50, if the vertical forces acting along D - B and E - C have as one of their components the femur shafts D-M and E-N in their proportional lengths, then it is correct to state that, though the other components may have a vary: :ing direction to the walls of the pelves as expressed by the sacro-acetabular lines or by the antero-posterior pelvic diameters, yet the angle between the two components will remain a constant. That is, that, per se, the width of the pelvis <u>should</u> <u>not</u> in the slight: :est degree influence the amount of divergence between the axis of the/

the neck and the axis of the shaft:[1] but what does follow is the difference in the obliquity of the neck of the femur. This tendency to the constancy of the angle of the neck of the femur is borne out in Table 6., where, within limits, the angle remains a constant for the adult.

TABLE 6.

	Pelvic index.	Angle.
	(aver.)	o.
Human.F.	94	127
" M.	95	125
Gorilla.	147.	120. (Duckworth gives 124°.)
Tigress.	134.	123.
Ass.	134.	127.
Deer.	158.	125.
Puma.	151.	128.

Explanation: The method of obtaining these measurements has been detailed before: Fig.51. shows how various measurements are taken.

In application of this constancy to the adult human subject, HUMPHRY'S first conclusion, "that the angle varies at any given age", is only too evident. In HUMPHRY'S series there was a range of degree from 113° to 136°, other writers as a rule admitting a similar variation. It is obvious that this variation is purely indiv: :idual, and is of much greater extent than that found between the average of man and other mammals. Individually there is variation in the breadth of the pelvis, (Table 3), in the length of the neck and in/

1. It is a significant fact that the angle which the morpho: :logical neck of the humerus makes with the shaft of the bone is in the human subject 125° - 130°.

in the length of the shaft, (Table 4.) but these variations can in no

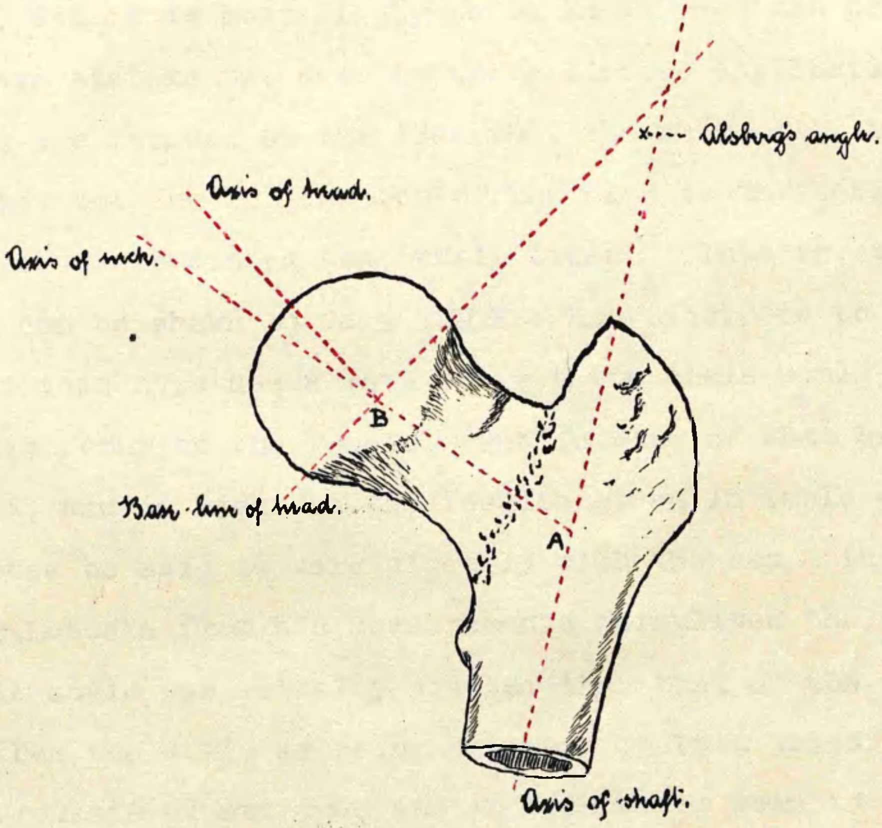


Fig.51.
To show how various measurements are obtained. The angle at A is the angle of the neck of the femur: A-B is the length of the neck.

possible manner be correlated to the variations of the angle.(1) The causes must be assigned to differences in individual developmental reaction, causes which can never lend themselves to proof.

Now as regards the sexual variations which are said to exist in respect to this angle, Humphry has summed up the accepted view/

1. HIRSCH, Anat. Hefte, Bd. 37., puts forward the view that a long neck is associated with a large angle. The same author correlates the angle and the area of the transverse section of the shaft. (op.cit. 1800, s.10.)

view in his conclusion, "that in short bones the angle tends to be small, and it is most likely to be small when the pelvis is wide". Both of these statements, even in their limited application to the human sub: :ject, are founded on the idea that the femur will be developmentally plastic, but the inclination of the neck to the horizontal has been con: :sidered as remaining absolutely fixed. That is, that the one factor which can be shown to vary HUMPHRY has concluded to be unchangeable, and if this hypothesis were correct the angle would be smaller in the shorter femur of the female. But in view of what has already been proved, and in light of the results given in Table 4., the angle can in no sense be said to vary directly with the sex. In his work on this angle, LUSCHKA from his measurements formulated the conclusion that the female angle was actually greater than that of the male: HYRTL de- :scribes the angle as being the same in both sexes: CHARPY in his measurements al att ages and in both sexes came to these conclusions: "The angle in the young person is greater than in the adult: in the adult it is the same for both sexes, on an average 127°: in the old person the angle is the same as for the adult." PARSONS in a recent series of measurements of 300 bones, found the male angle as 126.5° and the female angle as 125.5°, and states as his conclusion, "that the angle of the neck is of no value as an indication of sex".

In the study of the ontogenetic changes of this angle there is universal proof that the divergence is greater in young children than in the adult, and greater in the foetus than in the child. This change in the angle of the growing bone,- a decrease in degree concomitant with the increase in age,- is dependent on the controlling/

controlling influence of the mechanical over the developmental forces, By pure development the whole neck tends to be more or less directly vertical, or perhaps spiral: thus the open angle in the foetus, thus the open angle of the femur on which strain has never been put, e.g. HUMPHRY'S measurments in early amputations, paralysis, etc. Reference may also be made to skeletons 1 and 2 already described. On to this vertically directed neck there is transmitted through the head of the femur a shearing force, acting vertically, which is tending to produce an angle between the two components through which that vertical force is transmitted, and as a result of this there will be, not a bending of the osseous or cartilaginous tissues of the neck of the femur, but a difference in the plane of the epiphyseal cartilage of the head. This epiphysis is horizontally placed in the foetal bone, and to assume the adult oblique position, there is, as it were, a greater amount of growth at the outer end than at the inner end of the plate.(1) (This point will be more fully dealt with later).

Many authors also hold that there is a senile change, - a further reduction of the adult angle. Against this change HUMPHRY has written most conclusively, and on a series of measurements of senile bones bases the deduction, "that there is no tendency for the angle to collapse in old people". In other words, the mechanical and the developmental forces having acted up till the end of development in/

1. There are authors who hold to the idea that the main factor in the reduction of the angle is the pull of the ilio-psoas muscle. It can only be at the most of minor importance, as is evident from those cases of amputation below the insertion of the muscle, where the angle is still found large. (see Tubby, Orthop. Surg. Vol.1.p.260.)

in producing a structure best suited for the individual organism, there is, normally, no tendency for that structure to change. Substantiating Humphry's dictum there is the conclusion of CHARPY, "in the old person the angle is the same as in the adult." WARD writing on this supposed senile characteristic, says, "This change (the decrease of the senile angle) is not so constant as CLOQUET and other anatomists would seem to represent them: for on examining the thigh bones of very old sub: :jects in the dissecting room, I have found many entirely free from the described peculiarilies, and indistinguishable, in respect to form, from the femur of the well formed adult." BELL who first drew attention to the processes of interstitial absorption upon which these progressive metamorphosis depend, describes it not as a healthy action natural to the senile period of life, but rather as an abnor: :mal process incident to a debilitated or otherwise morbid condition of the economy in particular individuals. (The subject was consider: :ed in dealing with the internal structure of the bone.)

For surgical purposes what is known as Alsberg's angle, must be briefly described. The method of obtaining this quantity is shown graphically in fig.20. as the angle between the prolongations upwards of the axis of the neck and the base line of the head. The average size of the angle as found by ALSBERG is 41°, the variation extending from 25° to 54°. (It should be noted that in 1885 HENLE had described the angle between the line of the base of the head and the horizontal as measuring 40°.) In the present series, measured with the corrected base line, the average angle amounts to 42.5°, the range of variation being from 26° to 54°, a variation/

variation which is not correlated to the variation of the angle of inclination. The practical importance of this angle is said to lie in the changes which are produced in it in the conditions of coxa valga and coxa vara, for while in the former condition the angle increases in size in the latter it decreases or may even become a minus figure, the normal proximal convergence of the angle lines being then replaced by a divergence. It must be evident, however, that the angle of in-:clination need not be altered to produce a change in the size of ALSBERG'S angle.

The following classifications of the angle of inclination have been made for surgical purposes:-

TUBBY, Normal - 125°- 128°.
C.Vara - below 125°.
C.Valga- above 128°.

MICKULICZ.

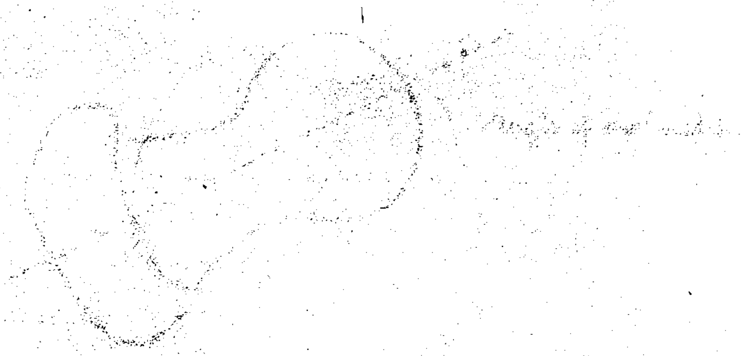
Normal	-	125°- 126°.
Frequently	-	120°- 133°.
Exceptionally	-	115°- 140°.

The following then are the conclusions arrived at in regard to the angle of the neck:-

1. The angle varies at any given age.
2. It is influenced by the breadth of the pelvis or the length of the femur, so that there is no sexual variation.
3. It decreases during the period of growth but after growth is completed there is no change.

4./

4. If the limb is not subjected to mechanical function from an early period the angle remains open.
5. The changes in the individual angle are dependent on the growth of the neck at the epiphyseal plate.



necessitate a limitation as wide as - 27° to 65° ,yet two-thirds of all bones may be placed between 4° and 20°.

As regards the causation of torsion, if one were to be led by CRUVIELHIER in his defined 'Law of Torsion', the twisted appearance of a bone,e.g.the fibula, would be taken to indicate that an actual torsion of the osseous fibres had determined the result, whereas the twisted appearance of the fibula is to be regarded as no more than a mere modelling of the external surface as a result of muscular attachment. For a complete appreciation of torsion,however, as expressed by the differences in the planes of the axes of the articular extremities, in the present instance the torsion of the femur, a study must be made of the torsion as it is found at the various periods of life, and of those pathological conditions in which, in this respect, the femur has deviated from the normal. For the former study extensive reference has been made to the work or Le Damany, certainly the most complete and detailed on this subject.

Table 7 details the amount of torsion at different ages. The method described by PARSONS (J.A.P.Vol.49) was used in the author's measurements.

TABLE 7.

	Le Damany.		Walmsley.	
	Rt.	Left.	Rt.	Left.
	o.	o.	o.	o.
Foetus.3½ Mths.	-4.	-3.	...	....
" 4½ "	20	20	....	....
" 6 "	7 to 22	10to 30.	....	....
" 8 "	43 to 50	50 to 55	40	42.
" 9 "	30	36	44	40
Child 1 year	34.	33	32	36
" 2 years.	42	20 to 42.	30	28
" 4 years	30	55	32	....
" 7 "	....	....	28	25
" 8 "	32	28	20	....
" 10 "	9 to 24	24	....	....
" 12 "	....	26.	16	22.

Note/

Note:- I have been unable to verify with any degree of accuracy the results obtained by LE DAMANY for the younger foeti, on account of the mobility of the cartilaginous epiphysis on the osseous diaphysis, no method of fixation having been found which could be relied on to represent the true condition at those early periods. It is perfectly obvious, however, that at early periods the torsion is absent or only small in amount.

The torsion of the femur is thus a product of intra-uterine life, being absent at the beginning of the fourth month but developing to a maximum of about 40° by the end of the ninth month. After birth, as is seen in the previous Table, there is a reverse process, a detorsion, so that the adult torsion is really persistent partial non-detorsion of an earlier condition. That this detorsion is due to the adaptation of the femur for mechanical function in the erect position with the posterior position of the line of gravity of the body as is shown by LE DAMANY is undoubtedly true, for there is the valuable evidence of those states in which from pathological causes the femur is no longer mechanically normal. As has been indicated in a previous section there may be deviation of the femur in either of two directions, for, the mechanical adaptation may be expressed excessively or it may fail expression altogether. As an example of the former state rachitis is pre-eminent, and here there is not only a complete detorsion of the foetal condition, but, as a

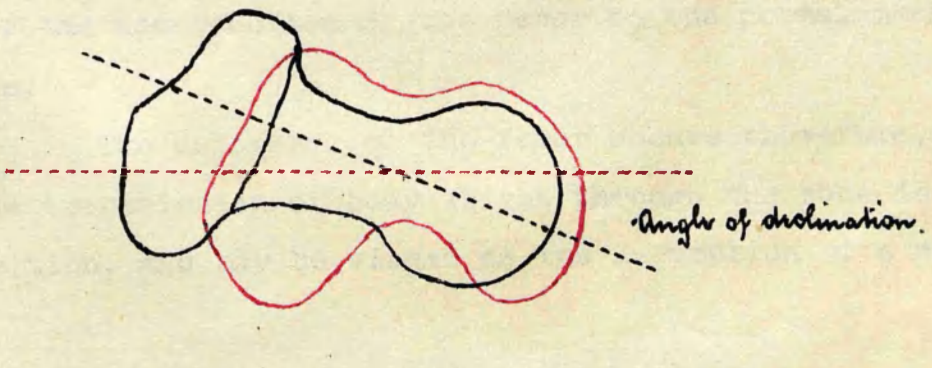


Fig.53.
To show the over-detorsion of the rachitic femur. There was a certain amount of coxa vara in this specimen.

a rule, an over-detorsion, so that the axis of the proximal extremity is from that of the distal extremity inclined backwards (fig.53.) The average angle of 10 rachitic femora I measured was found to be 8°; a specimen as high as -35° being the maximum, but other writers have recorded an even higher average and a maximum as great as -52°. In one specimen of osteomalacia which I have examined the backward in:
:clination was excessive, amounting to 60°. It is well to note that even in the most advanced over-detorsion of the femur, the leg is not carried in the position of internal rotation. As regards the other condition, where there is failure of the expression of the mechanical adaptation, the best example obtains inwhat is termed "congenital dislocation of the hip". For, whatever may be the individual author's view of the etiology of this condition, there is universal agreement that the neck of the femur is markedly anteverted,and remains so; and among those who detail the actual size of the angle there is a uniform:
:ity of the given figure as from 45°to 55°. This is exactly the size of the angle at the 9th.month of foetal life as obtained by LE DAMANY and by the writer, so that no longer should this excessive ante-ver:
:sion of the femoral neck be considered as a secondary product of the dislocation, as is at present held, but must be described as the ex:
:pression of the non-reaction of the femur to the normal mechanical requirements.

The detorsion of the femur occurs,therefore,in rela:
:tion to the transmission of body weight through the bone in the ex:
:tended position, and may be viewed as the assumption of a new rela:
:tion/

relation to the proximal epiphysis to the diaphysis during the growth of the neck of the bone. The change must be due to the unequal growth at the epiphyseal plate, and as such is indicated in the adult bone by the convexity forwards of the neck. The detorsion will not only allow of the conversion of the foetal flexion into the extension of the post-infantile period and thus bring the lower end of the femur more into the line of body gravity, but will also allow of the change of the foetal position of internal rotation to the subsequent position in which the leg is turned slightly outwards. We would thus uphold LE DAMANY'S contention that the foetal torsion is the direct result of the position of flexion into which the foetal limb is thrown.

2. <u>THE AXIS OF THE HEAD</u>.

It has been shown in treating of the angle of the neck of the femur that the axis of the neck has an inclination to the vertical which varies according to the breadth of the pelvis, and that the axis is more oblique in the broad than in the narrow pelvis. The cause of the variation of the obliquity of the femoral neck has been indicated as the association of the constancy of the angle of the neck with the differences in the inclination of the shaft necessitated by the differences in the length of the femoral neck. OWEN in his consideration of the limb skeleton of the gorilla remarks, "the neck (femoral) in the gorilla is less oblique than in the human subject": and CRUVIELHIER has pointed out that in the human subject the obliquity is greater in the female than in the male. As a point of practical importance it may be noted that the line of the axis of the femoral neck of the human subject may be determined as the lateral part of the line joining the base of the great trochanter and the mid joint of the 'interspinous line'.

The obliquity of the femoral neck in the human subject is such that when the axes of the necks are prolonged inwards they intersect at a point far back on the antero-posterior pelvic diameter;/

diameter; but as the pelvis narrows this intersection occurs nearer to the inter-acetabular line. (figs. 54.55, and 56.) This means that there is in pelves of differing indices a difference of the inclination of the axes of the femoral necks to the lines of weight transmission from the sacro-iliac joints to the acetabula, and this difference is such that the broader the pelvis the more nearly in one line will the axis of the neck and the cotylo-sacral line be placed. Depending on this difference is the varying inclination of the axis of the head of the femur to the axis of the neck.

Fig.54 (a).
Human Pelvis.

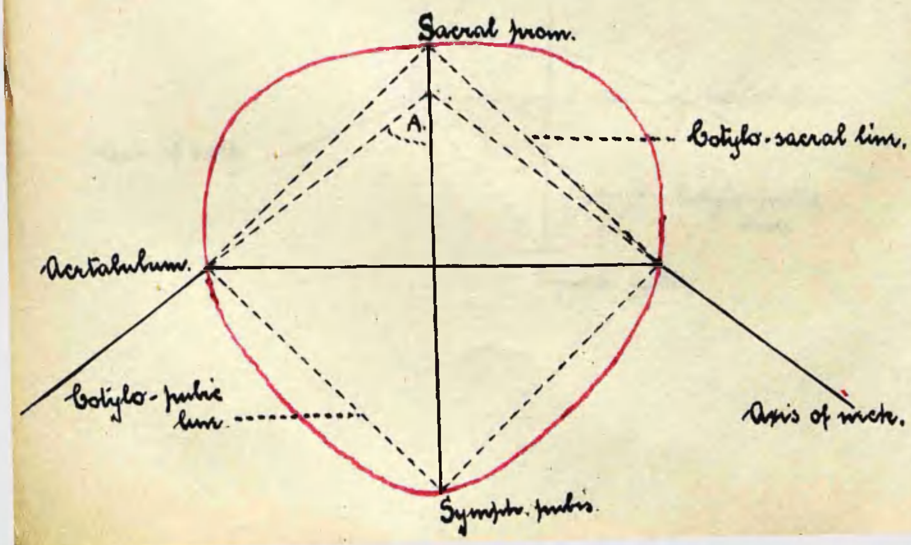


Fig.54.(b).
The above pelvis has been drawn to scale & shows the point of intersec:
:tion of the axes of the femoral necks.
Angle at A–39°, (average of eight specimens; KRAUSE found it 41°.)

Fig.55.(a).
Pelvis of Gorilla.

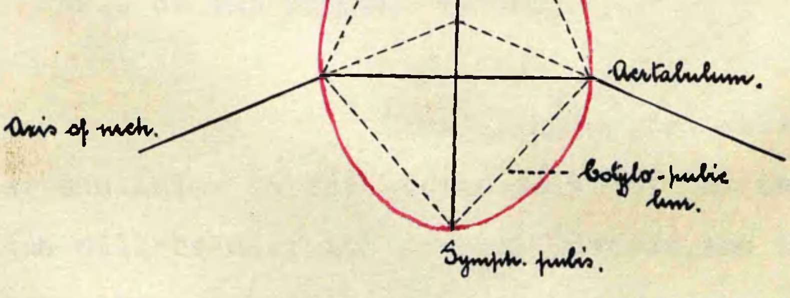


Fig.55.(b).
The pelvis of the gorilla has been drawn to the same scale as fig. 54. and shows the point of inter: :section of the axes of the femoral necks.

Fig.56.(a).
Pelvis of Tigress.

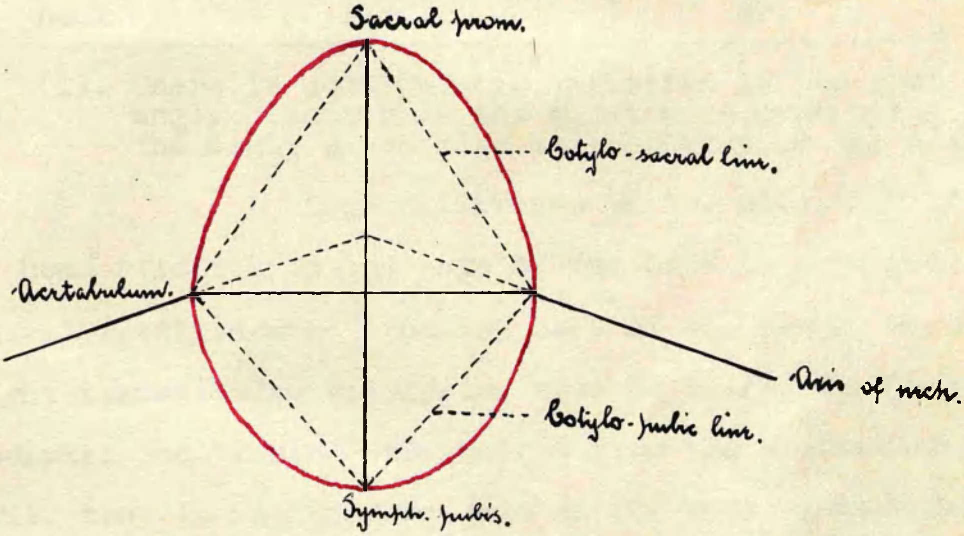


Fig.56.(b).
The pelvis of the tigress has been drawn to the same scale as figs.54 and 55 and shows the inclination and intersection of the axes of the femoral necks.

The morphological axis of the head is the line perpendicular to the centre point of the base line of the head, and as such will be directed upwards, inwards, and slightly backwards. (vide. 'base line of head').

In fig.51. it is shown that in the human subject this axis of the head is in the perpendicular plane, inclined to the axis of the neck at an angle of 5° (average figure,) and Table 8 shows the increased size of the same angle in a series of animals with relatively narrow pelves.

TABLE 8.

	Pelvic index.	Angle of head.
Human.M.	95. (aver.)	4.4° ..(1)
Tigress.	134.	18.
Puma.	151	24.
Ass.	134.	22.
Deer.	158.	22.

(1). There is considerable variation in the size of this angle; figures on the minus side even being found. The angle given aims at representing the mean.

This difference in the obliquity of this axis of the head relative to the axis of the neck is a response to the mechanical requirements: for the head of the femur, as a pressure or weight transmitting epiphysis, will be placed in the position best adapted for "taking" the weight from the acetabulum, and so its axis will tend to lie more or less in the sacro-acetabular line. Thus in lower animals the axis of the head is, relatively to the axis of the neck, much more vertical than in the human subject, and the epiphyseal cartilage is almost horizontally placed. In the foetus of the human subject the same condition is found, so that in addition to the large angle of inclination, the axis of the head is directed almost vertically upwards. Till the end of the first year there is little alteration of the femur in these respects, and the/

the epiphyseal cartilage will be found horizontal in position even as late as the third year. After this period, however, the cartil: :age comes more and more to occupy an oblique position, so that before its final absorption it slopes downwards and inwards at an angle of at least 40°.(1) As causative of this change there has been indicat: :ed the greater growth at the outer end of the epiphyseal cartilage, and as a direct result of the change in position there are two alter: :ations in the form of the femur. Firstly, there is the progressive decrease in the angle of inclination of the neck and secondly there is the change in the position of the axis of the head. The head, transmitting the same force as before, becomes "tilted over" to the oblique adult position, so that at that period of life, 10 to 14 years, while the cartilage is in the adult obliquity yet still car: :tilaginous, there is the greatest tendency to the occurence of the condition of "traumatic slipped epiphysis".

That "slipped epiphysis" does occur from purely traumatic causes is now universally admitted, with singular agreement as to the age of greatest frequency, the only differences of opinion being as to the relative frequency of occurence compared with frac: :ture of the neck. It is interesting to note that JOHN BELL, (Edin). 1793, Anat. of Bones, Muscles, and Joints, makes this remark: "...falls separate the head of the femur in young people, but break the neck of the bone of those advanced in years." WHITMAN says the condi: :tion is not very common, but the greatest number of cases occur between/

(1). In fig.51. if 'Alsberg's angle' is 42°, and the inclination of the axis of the shaft 5°, then the inclination of the cartilage to the horizontal would be 43°.

between the ages of 10 and 14 years. HOFFA mentions exactly similar facts and figures. SPRENGEL describes the condition as more fre:quent, but again as most frequent between the 10th. and 15th.years.

The morphological axis of the head,then, is not a continuation of the axis of the neck, but is placed more vertically even in the adult human subject. Its orientation is so dependent on mechanical causes that throughout the mammalian series it is placed, in the adult, in the sacro-acetabular weight transmission line. In the human subject it is at early periods almost vertical, and acquires its adult obliquity by an unequal growth at the epiphy:seal cartilage of the head.

The axis of the head thus considered is in rela:tion to one aspect only of its function,- that of "weight reception", and as such was termed "the morphological axis". In its function of movement however the head will possess axes of its planes of move:ment,and that of flexion is not coincident with that of structure, as is assumed in the "ball and socket" theory of rotatory movement.

In a destructive though erroneous criticism of the view of SIR CHARLES BELL in regard to the neck of the femur being essentially a static structure the exponents of the "ball and socket" theory have, for themselves, decided the functional causation of the neck. We quote freely from MORRIS. The first fact of importance in the causation of the neck is in order that angular movements of the shaft (flexion) will be converted into rotatory movements of the head: diagrammatically this "movement conversion" view is express:ed in fig.57. Purely forward angular movement of the shaft with a/

a 'straight-set' head (A) would determine an angular motion of the head, so that femoral flexion to one-half would be coincident with a displacement to one-half of the head of the femur from the acetabulum. (B). If the head is set at right angles to the shaft by means of a

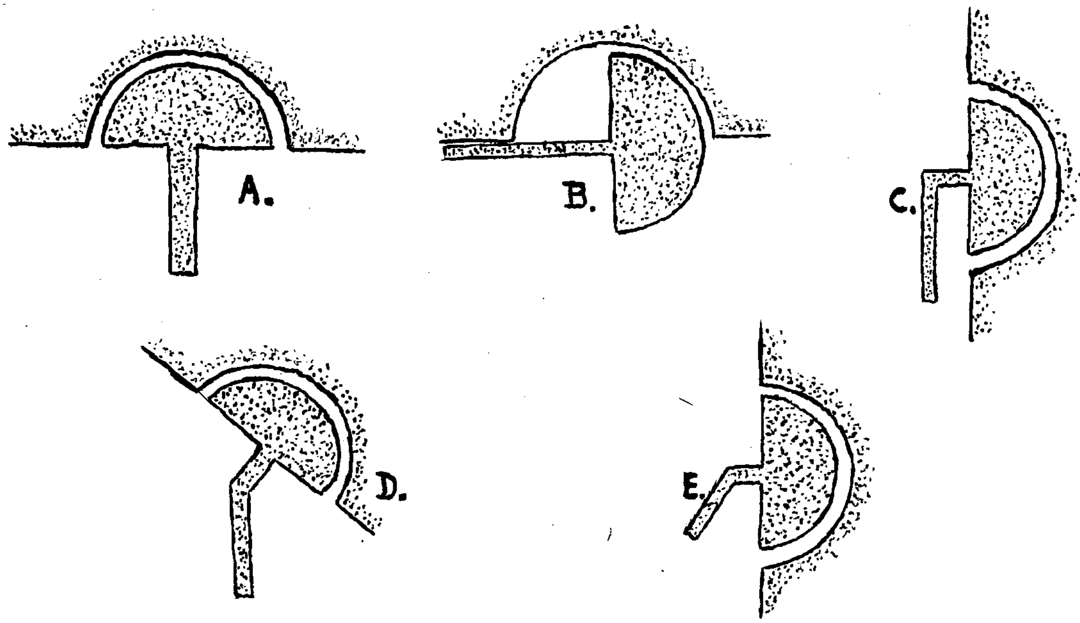


Fig.57.

neck(C) purely angular movement of the shaft is said to be reproduced as pure rotation of the head about the axis of the neck and thus ob: :viate diminution of articular surface contact/in flexion in the absence of dis: :placement of the head from the acetabulum. In the actually occur- :ing conditions, however, the angle of the neck is not one of 90° but approximates 125°, represented as in (D) or (E) and the writers claim to have shown that the movement of the head within the acetabulum is one of rotation round its coronal axis, which is coincident with a prolongation of the axis of the neck. In this however there is ob: :vious/

obvious fallacy; for there has been a total disregard of these facts: that the axis of the neck is not in the same vertical plane as the transverse axis of the shaft (torsion of the femur): that the movement of flexion may not be purely vertical: that the plane of the vertical movement of the shaft is not parallel to the base of the head: in addition it will be shown that the head of the femur is not uniformly circular, nor is the acetabulum truly spherical: All these are factors which individually would preclude a true rotation of the head of the femur round the axis described and all individually would cause a displacement of the head of the femur from the acetabulum in flexion if it occupied that cavity in extension, or vice versa: for there is the fallacy of the assumption that the shaft is moving round some fixed point, variously placed on the great trochanter, when it is so obvious that there can be no fixation of the femur at all apart from the reception of its head in the acetabular cavity. The axes of movement of the head must only be determined from its curvation.

3. THE CURVATURE OF THE HEAD AND THE AXES OF CURVATURE.

It is a recognised fact that the head of the adult human femur is not absolutely spherical. MACALISTER mentions the difference of 1mm. between the radii of circles representing coronal and horizontal sections, and somewhat similar results were obtained by AEBY, SCHMIDT, KRAUSE and others. All agree on the irregularity of the curvature of the head. KRAUSE after a most minute examination supports the conclusion of AEBY that "the head is not everywhere of the same curvature, but is most closely described as an oblique pole segment of a rotation ellipsoid." The figures given by SCHMIDT and by AEBY are as follows:

Radius of ant.-post.section ......M.27 mms.
F.24.5 mms.

Radius of vertical section ......M.26 mms.
F.23 mms.

GOODSIR in describing the curvature of the head says, "if the outline of the transverse and antero-posterior diameters of the head of the femur be followed by the eye against the light, it will be observed that they are not arcs of a circle." MEYER also maintained that the head was not a true sphere, believing that the body weight in the erect posture falling on the supero-posterior area of the head would cause that area to become flatter, while on the inferior surface a strip will be depressed by the pressure of the ligamentum teres. HYRTL also upholds the departure from the true sphere, for he states "if the head of the femur be called a sphere this expression cannot be taken literally; it is not a sphere but an ellipse of three curva:
:tures of different radii." Each of these authors emphasises in his/

his own way that the departure of the head from the sphere will in-:fluence the working of the joint. FICK in discussing this subject calls attention, though not exactly with cause, to the disagreement of previous workers even as to the greatest or the smallest measurement, and holds that any irregularity which is present is rectified by the articular cartilage, and is therefore of absolutely no moment in the mechanism of the joint. As already indicated, however, the shape of the articular surfaces of the joint is the ultimate determinant of its mechanism.

In obtaining the various curvatures given below various means were tried, but the most satisfactory results, those which were finally adopted, represent tracings of actual sections of the bone at the desired level. In all cases the head of the femur in as fresh a condition as possible was used, so that the articular cartilage was present in as near the normal form as it was possible to obtain it.

Even at the risk of a subsequent repetition it will be necessary to indicate in this place the orientation of the head of the femur within the acetabulum, especially in the erect position. In the act of walking or in the adoption of the most com:fortable position when standing erect, the medial sides of the heels are more approximated than are the toes, so that the femora are in a position of slight external rotation. When this rotation is trans-:lated to the superior extremity of the bone, it will be found that together with the torsion already present, the necks of the femora are made to point as much forwards as inwards. So that in defining the/

the curvature along which the head of the bone is acting, care must be

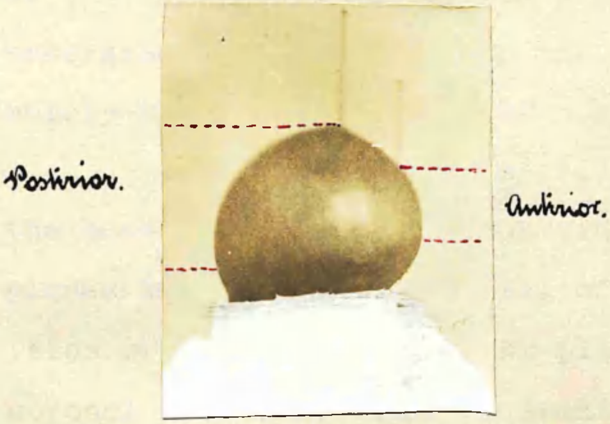


Fig. 58.
Photograph of an antero-post.plane at right angles to the plane of movement of the head,and through the highest point of the teres fossa.

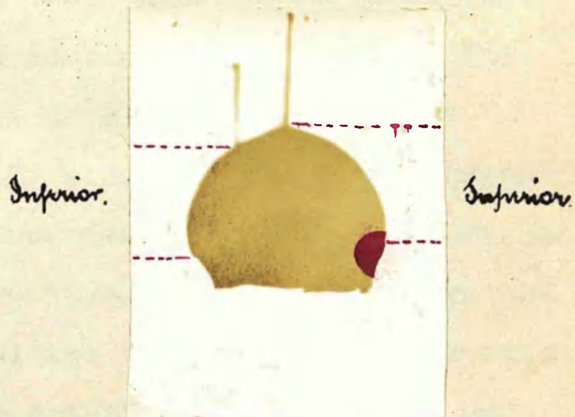


Fig.59.
Photograph of a coronal plane at right angles to the former,and through the middle of the teres fossa.

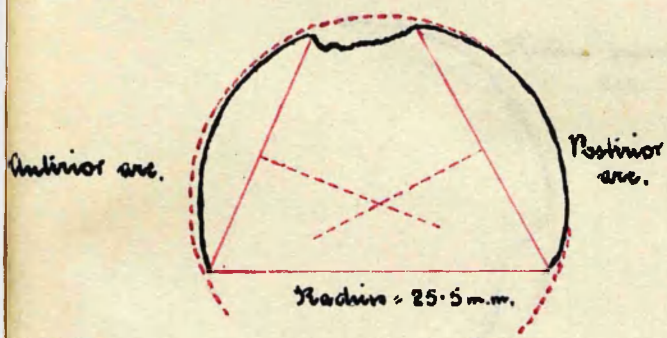


Fig.60.
Tracing of an anter-postsection in a plane at right angles to the plane of movement of the head,and through the highest point of the teres fossa. (adult male.)

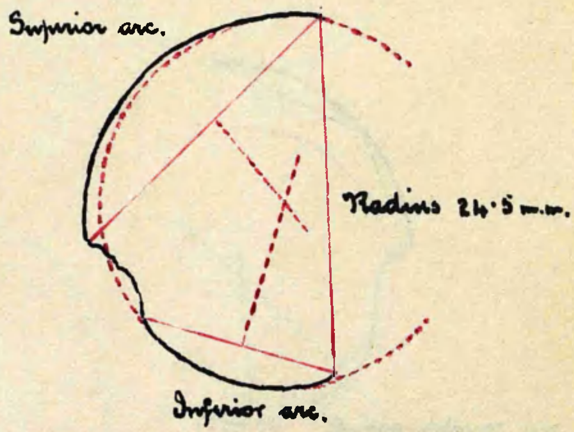
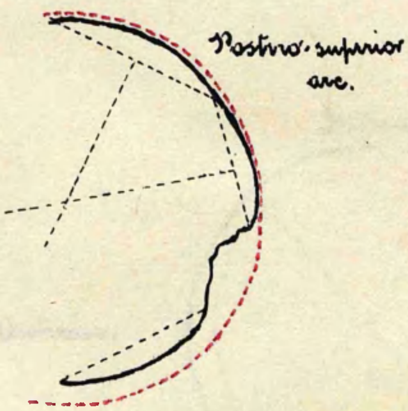


Fig.61.
Tracing of a coronalsection at right angles to the for: :mer,and through the middle of the teres fossa.(Adult male,same as fig.36.)

taken to make the section in the appropriate plane,which is not at right angles to the morphological axis of the head and parallel to the/

the articular margin, but inclined to the axis at about, on an average, 42°. A description of the plane of each section is given and it will be understood that though only one such section may be figured this is merely the representation of a series of similar sections.

These two sections (figs.60 and 61,) demonstrate that the head of the femur is not truly spherical, sections in different planes having different radii of curvature. Now not only does the section of an antero-posterior plane differ in its radius from that of a coronal plane, but what is really important is that what ~~is~~ are described as the circles of these sections ~~is~~ are in each case made up of two arcs of different radii, and the change of curvature takes place at the fossa for the ligamentum teres. That is evident from the photographs shown, and is demonstrated in figs.62 and 63.



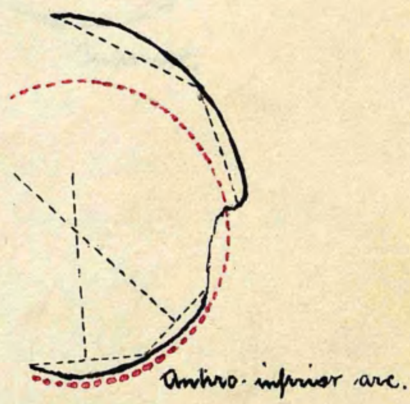


Fig.62 Fig.63.
Tracings of sections passing through the centre of the head so as to bisect the postero-superior and antero-inferior quadrants, the bone being orientated in the erect position.

From a large series of sections made in different planes it was determined that the arc of greatest curvature is that of the/

the supero-posterior part of the head, while the arc of smallest radius was that portion of the head of the femur below and anterior to the fossa for the ligamentum teres.

The next series of sections were made parallel to the base line of the head at varying distances from it, so that trac:ings were obtained of the whole circumference of the head at right angles to its morphological axis (figs.64.and 65.)

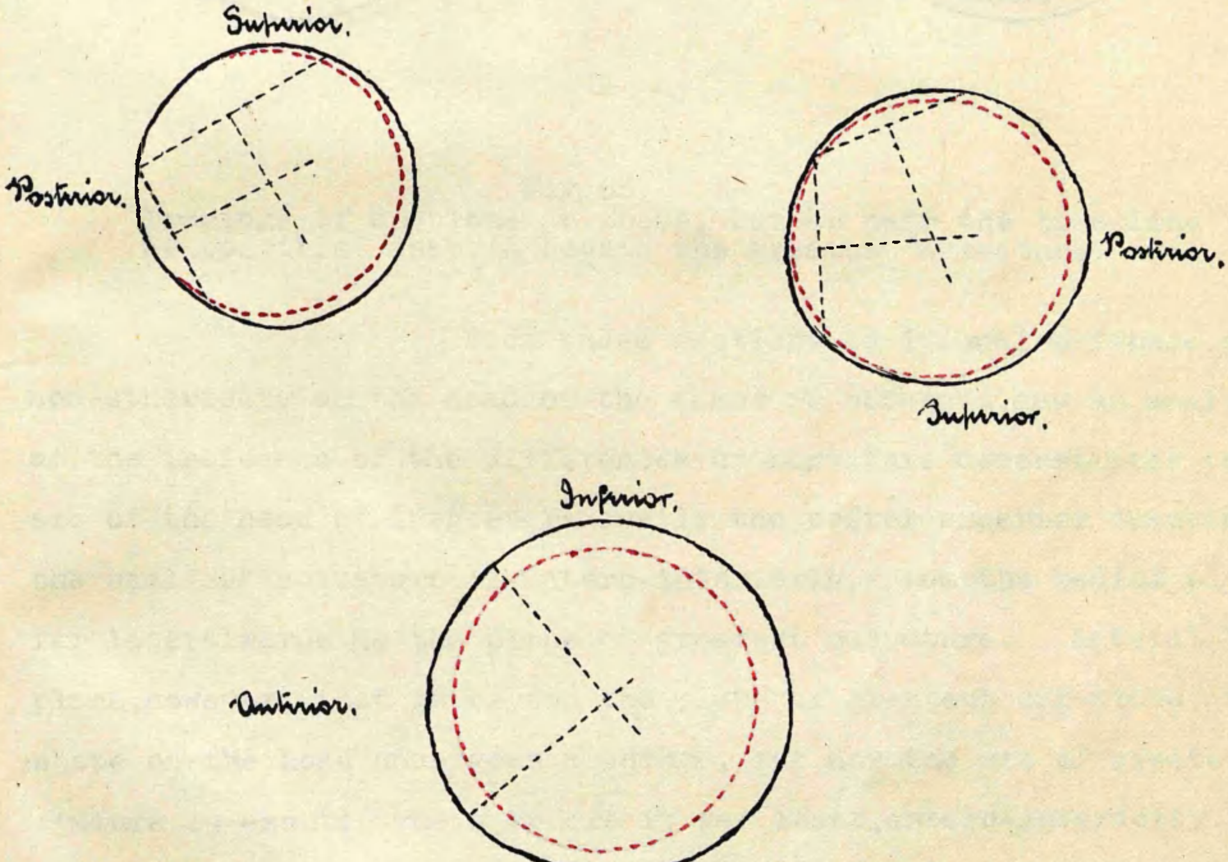


Fig.64.
Tracings of sections parallel to the base line of the head at right angles to the axis of the head: A, as far medial as possible: B, an intermediate section: C, through the plane of greatest curvature.

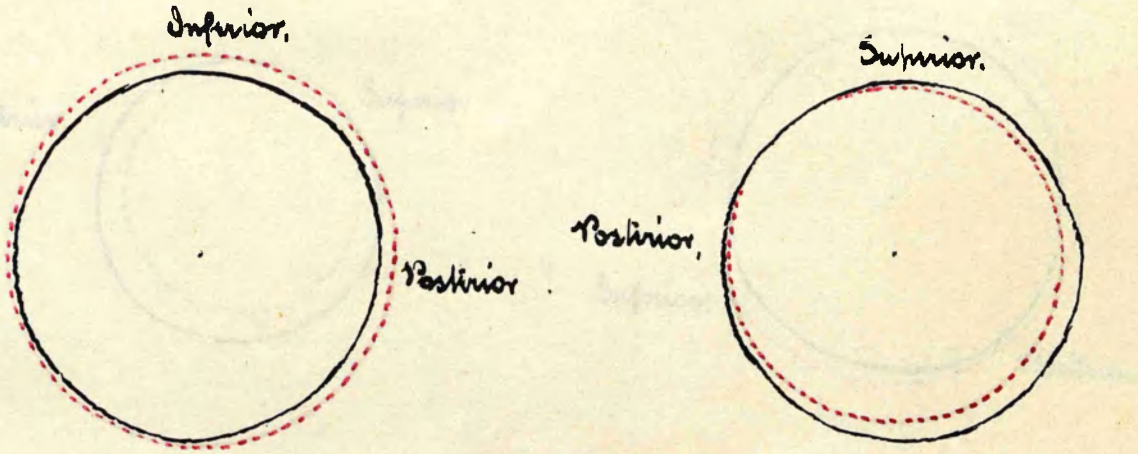


Fig.65.
Tracings of sections as above, but as near the base line as possible, that is beyond the greatest curvature.

From these sections additional evidence of the non-sphericity of the head of the femur is obtained, and an analysis of the incidence of the differences of curvature demonstrates that the arc of the head of largest radius is the poster-superior quadrant, and the smallest curvature is antero-inferiorly, from the medial plane as far lateralwards as the plane of greatest curvature. Lateral to this plane, however, that is beyond the plane of greatest curvature, the shape of the head undergoes a change, for now the arc of greatest curvature is exactly where before it was least, antero-inferiorly.

Lastly, sections of the head were made in the plane of movement. (fig.66.) These show in a more marked degree a departure from the spherical, whose incidence corresponds exactly with that previously demonstrated.

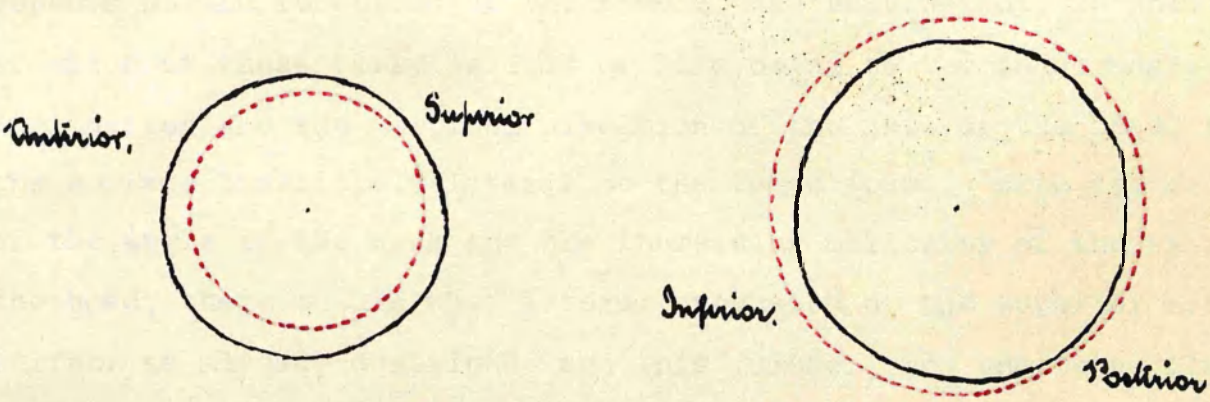


Fig. 66.
Tracings of sections through the plane of movement.

Before the head of the femur is considerably ossified, we have found it impossible to determine with accuracy its exact curvature. In the foetus and up till the period at which the child begins to walk the head of the femur appears to be spherical, (fig.67.) but subsequent to this period it was found that there was a gradual flattening out of the supero-posterior quadrant, increasing the curvature of that arc. (fig.68). This flattening out depends

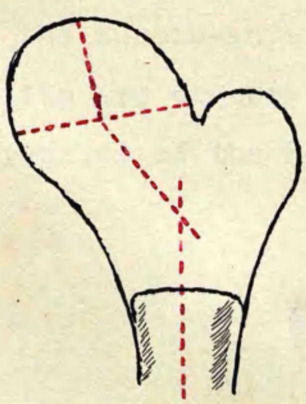


Fig. 67
Proximal end of femur at birth.

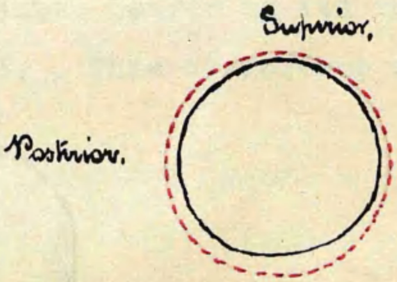


Fig. 68.
Section of the head of the femur at 5 years, in the plane of movement.

depends on the reception of the transmitted body weight, the incidence of which at these early periods of life, owing to the large angle of inclination and the vertical direction of the axis of the head, is on the surface immediately lateral to the teres fossa. With the decrease of the angle of the neck and the increasing obliquity of the axis of the head, there occurs that lateral expansion of the superior articular surface as already described: and this further area undergoes flatten:ing of its arc of curvature from the new incidence of the body weight. The original flattened area, now being directed towards the pole of the sphere, does not undergo a further relative increase of its radius of curvature, and so the differences of curvature in the plane of move:ment are less marked towards the pole of the sphere than towards the plane of maximum radius. We have been unable to determine any flat:tening on the inferior articular surface beyond the teres fossa, as suggested by MEYER.

A minute comparison with the curvature of the head in quadrupeds has not been attempted, but the curvature in the gorilla affords an interesting comparison with the curvature in man. In the gorilla the supero-anterior area of the head is distinctly flattened, so that its arc of curvature is 4mms. longer in its radius than that of other parts of the head. (AEBY). This difference of the incidence

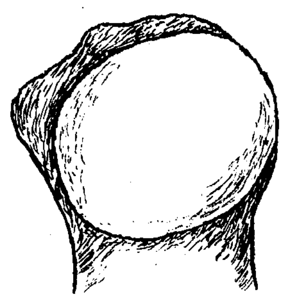


Fig. 69.
Pole view of the head of the femur of the gorilla. (after AEBY.).

incidence of flattened area is no doubt due to the difference of the incidence of the body weight on the flexed femora of this species.

From the different sections described, from the reference made to its ontogeny, and from a comparison with the cur:
:vature in the gorilla, it has been resolved, that the head of the femur is not spherical in the adult human subject: that it should be considered as the compound of different areas, or acting facets, that of largest radius being supero-posterior and the smallest antero-in:
:ferior: and that the differences of curvature of these areas are of such a magnitude as will determine that separate incidence of action which is necessary in an organised articular couple. A definition of the separate "areas of action" can only be founded on an accurate knowledge of the relationship which the head of the femur bears to the acetabulum in all positions of the joint, so that the incidence of the areas of congruity of the opposing articular surfaces and the position of the limb in which the congruity occurs may be known. We propose, however, to recognise that the head of the femur is not spherical: that its greatest curvature is postero-superiorly: that this curvature decreases gradually and in a uniform manner when traced anteriorly or posteriorly, and reaches its minimum in the antero-inferior quadrant.

In determining the geometric form to which the head of the femur most closely attains, it is necessary to orientate the peripheral curvatures on their axes. The principle axis of the head is the line from the centre of the base line through the centre of mean curvature of its planes, and traced in a medial direction indicates the apical pole.

This axis does not coincide with the morphological axis of the head but has a horizontal inclination from it: it is the axis of the movements of flexion and extension and determines the apex of the head in the region of the anterior angle of the teres fossa. (fig. 70.) Revolving round this axis is a radius of constantly varying dimension maximal in the postero-superior quadrant and minimal antero-inferiorly, since sections at right angles to the axis were not spherical and similarly extensive arcs of the surface measured from the pole of planes through the axis were not identical in curvature. The head is not therefore

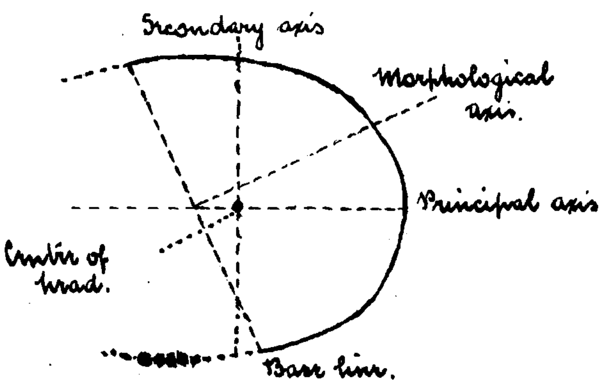


Fig. 70.

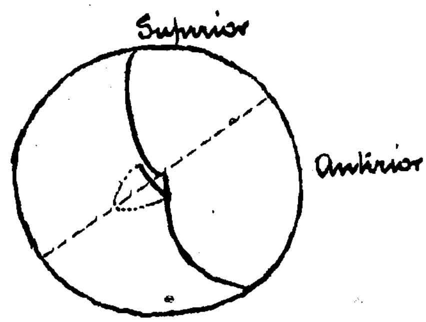


Fig. 71.

a pole segment of a rotational ellipsoid. We beleive that it is most closely described as the compound of two ellipses on a common axis which in direction is at right angles to the line of the teres fossa ligamentous attachment: and that the twoareas, thus separated, constitute the acting facets of the head of the femur.(fig. 71.) Even this description, however, is only approx:
:imate, but it expresses the increase of curvature of each arc towards the pole in sections of planes through the principle

axis, and distinguishes the change of curvature of the surfaces in sections at right angles to that axis.

4. THE POSITION OF THE ACETABULUM.

The position of the acetabulum must be determined in relation to two factors: first in relation tothe weight transmission of the body, concerned in which are the mechanics of the pelvis and the mode of the further transmission of the body weight to the structural axis of the head of the femur: and second, a position relative to the movements of the head as determined by the relation of its axis of curvature to the axes of movement of the head of the femur. The latter point is included in the consideration of its curvature.

The pelvis as a weight transmitting structure: As already indicated in dealing with the length of the neck of the femur, the position of the acetabulum varies according to the relat:
:ive breadth of the pelvis:[1] so that in a broad pelvis

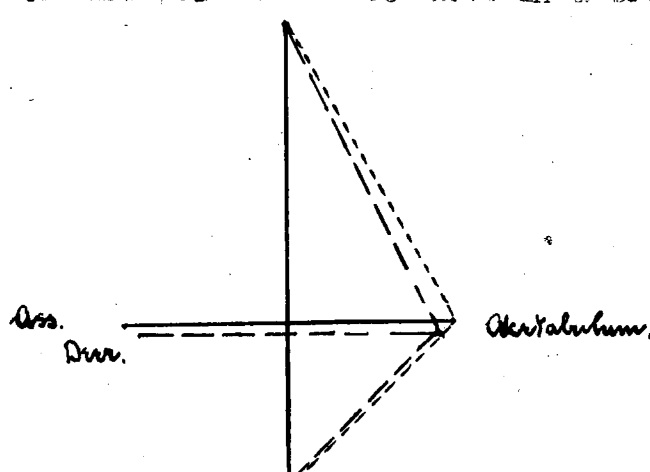


Fig. 72.
Comparison of the pelves of the ass and the deer,

1. Compare figs. 43, 44, and 72.

the inter-acetabular line is placed more posteriorly than in a narrow pelvis, associated with which there is a greater divergence of the pelvic lines of weight propagation. These facts lead to the definition of the statics of the pelvis in the erect position: that the non-weight bearing, though strain resisting, anterior parts depend for their conformation on the weight transmitting posterior parts.(1) Taking fig. 73 as representing two imaginary

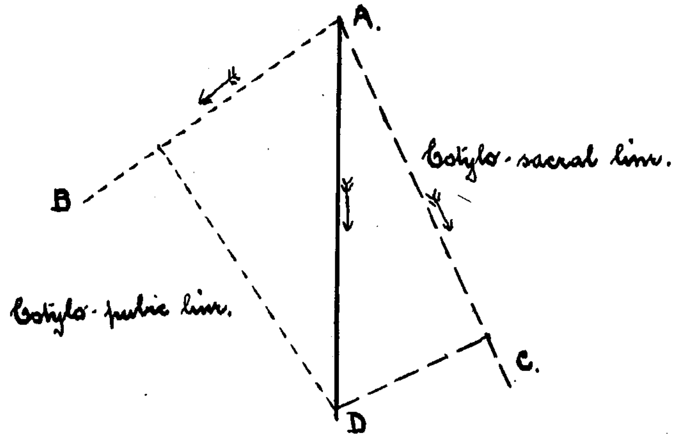


Fig. 73.
To show the effect of the amount of divergence of the weight transmission lines on the conformation of the anterior parts of the pelvis.

pelves, a wide A - B and a narrow A - C, then owing to the difference of divergence of the weight transmitting lines there will be a difference in the inclination to the vertical of the other component of that vertival force of which A - B or A - C forms the actual transmission line, and the more vertical the one component the more horizontal will that other component be, but

1. For the mechanics of the pelvis reference may be made to WOOD,S article on the pelvis in TODD,S Encyl. of Anat. where, though not stated, the inference here drawn receives full support.

the angle between the two components should remain a constant. Thus a narrow pelvis requires a long post-acetabular as compared with the pre-acetabular part of the antero-posterior diameter: and as the pelvis broadens, the further back will the transverse diameter be placed. On Table 9 results on this point are given for the human subject: and fig. 74 (drawn to scale) represents graphically that the differences of position of the pelvic static lines are coincident with the variation of the acetabular position.

TABLE 9.

	Ant.-post.	Post.acet.	Pre-acet.	Trans.	Index.
	cms.	cms.	cms.	cms.	
M...	9.6	3.9	5.7	10.7	90.
M...	11.8	5.8	6.	11.7	100.
M...	10.3	5.4	4.9	10.8	95.
M...	9.9	5.	4.9	10.4	95.
F...	11.8	5.8	6.	13.	91.
F...	12.	6.4	5.6	12.5	96.
F...	11.	5.8	5.2	11.5	95.
F...	12.4	6.3	6.1	13.1	94.

<u>Explanation</u>: The various measurements of this table aare taken exactly as laid down in the explanation of table 2.

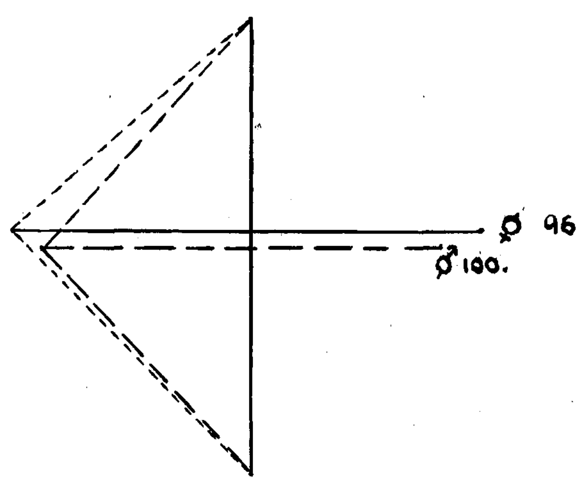


Fig. 74.
Comparison of human ♂ and ♀ pelves.

The position of the acetabulum on the pelvic wall is thus definite, and being defined by the relative breadth of the pelvis sexual differences are to be expected in the adult human subject. Its axis, in this sense, is the continuation of the sacro-acetabular line in which line the morphological axis of the the head of the femur lies, and it may be determined as the line at right angles to the centre of the weight transmitting area, the supero-posterior quadrant.

5. THE CURVATURE OF THE ACETABULUM.

To obtain the curvature of the articular acetabulum section tracings were analysed. It is only necessary to indicate those sections at right angles to its axis, fig.75, to to demonstrate that the continuous curve is not spherical. Again if sections are made through the axis it may be determined that the arcs are not placed on spherical lines, but would lie on an elliptical boundary, the increase of curvature taking place towards the acetabular fossa. The articular acetabulum we would hold to be the converse in form of the femoral head, the surface being divisible into two areas most closely described as elliptical in curvature.

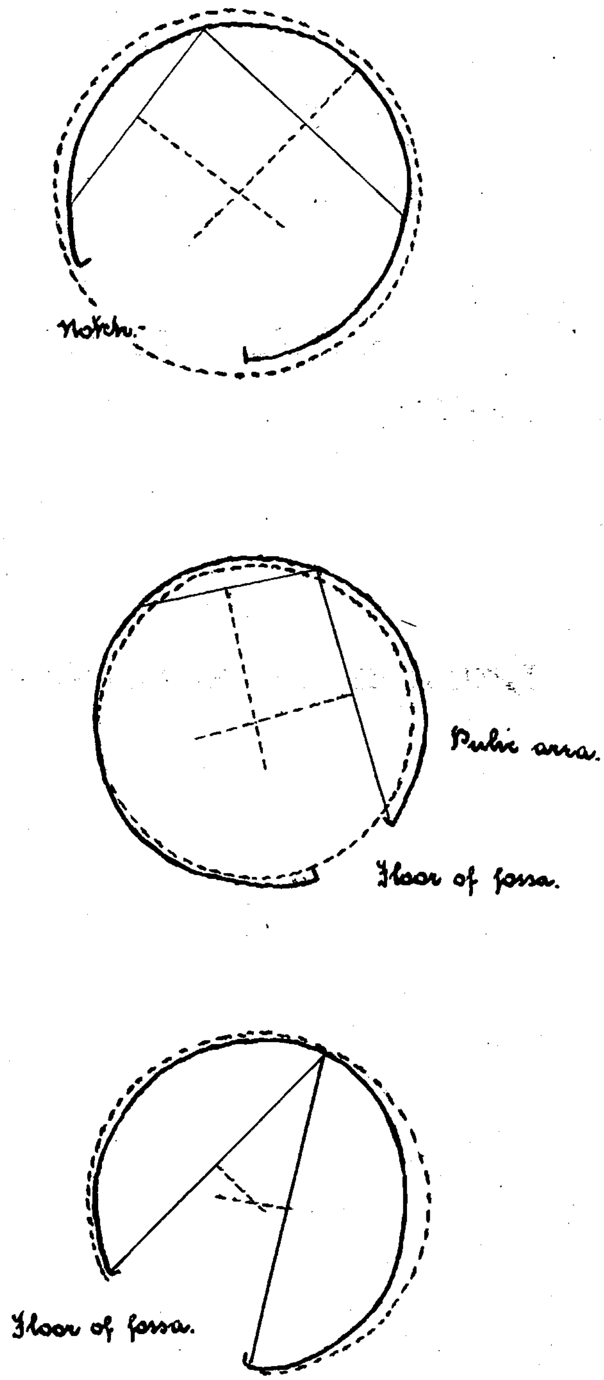


Fig. 75.
Sections at right angles to the axis of the acetabulum showing the non-sphericity of the articular surface.

P A R T   F O U R.

"THE MECHANISM OF THE HIP JOINT."

THE MECHANISM OF THE HIP JOINT.

The osseous elements of the hip joint are not developed to the same extent, the acetabulum being deficient: and the incomplete portions are replaced by yielding and movable structures. This restriction is possible since the whole of both surfaces is not essential for the development of their action, and is referable to the principle of economy of organic structure. The articular surfaces have been shown to be not continuous curves but to be compounded of separable areas, and the curvatures of opposing areas have been described identical, so that their reciprocal configuration will determine the movements of the bones relative to one another within the joint. Of each surface we have indicated that it is possible to differentiate two areas of facets, one postero-superiorly and the other antero-inferiorly, and the corresponding opposing surfaces being related only to one another in action the combin:ation constitutes an articular couple: so that what may be determined of the movements of one facet will be referable conversly to its complement.

By the study of the relations of plaster casts of its surfaces and by observation of sections of the complete joint during their movements, it may be determined that the postero-superior articular couple is in action during the movements of flexion and extension from the mid position, and that during this excursion of movement the antero-inferior couple is inactive since its surfaces are not in contact, that is are incongruous. KONIG has conclusively demonstrated the incongruity by sections of the frozen joints and the finding of thick layers of synovia between the surfaces. Beyond the mid position of the limb the postero-superior area of the femoral head passes on to the yielding transverse ligament and the antero-inferior facet comes into action on the complemental area of the acetabulum. We shall confine ourselves to the study of the movements of the former area.

The lines along which the head of the femur acts round its principle axis may be represented, in relation to a circle placed externally, by that series of curves which were shown to represent its sectional circumference. (fig.76 A.) The movement of extension, or the anterior revolution of the head, is therefore along a curve gradually decreasing in radius, so that when the antero-inferior quadrant is reached the continuation of the curve is in completion of a right-winding spiral: (fig.76 B.): or in the reverse movement of flexion from the extended position there is a simple unwinding along the same path,- a right-winding spiral in the right joint. LANGER, HENKE, and MEISSNER have each shown that the joint surfaces of the elbow and the ankle are of screw configuration while GOODSIR has described the knee and has indicated the hip as acting through similarly conformed surfaces. The demonstration of the actual curves of action of the head of the femur may be carried out in the manner elaborated by LANGER for the upper surface of the astragulus. A steel point is made to project sufficiently beyond the acetabulum to produce markings on the femoral head when the limb is moved through flexion and extension from the mid position, and the

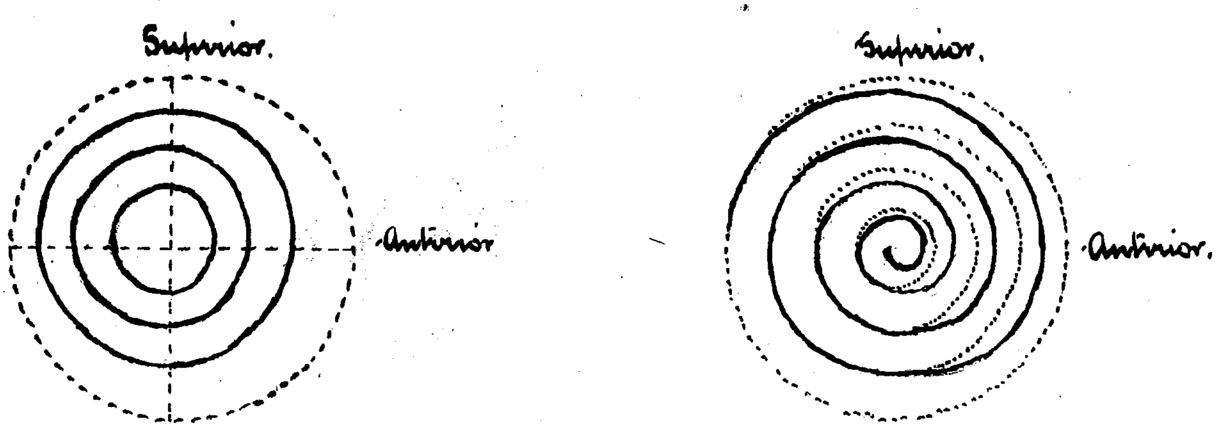


Fig. 76.
The lines of curvature along which the head of the femur may be supposed to act.

curves so obtained are combined with one another so that the prolonged line represents the configuration of the whole surface. The result of such an experiment is represented in fig. 77, and substantiates the conclusion "that the head of the femur rotates along a right winding screw curve in extension of the right joint."

During their action the elements of the couple will therefore glide past one another in two directions so that the actual movement observed or recorded is the resultant of two component movements.(1) The more extended is the primary movement and determines the lengths of the facets: the other is the secondary movement and determines their breadths. The resultant or actual movement as already indicated occurs alternately in opposite directions along the same path, but in one direction to the establishment of the maximum of congruity which is total , in the other direction to the

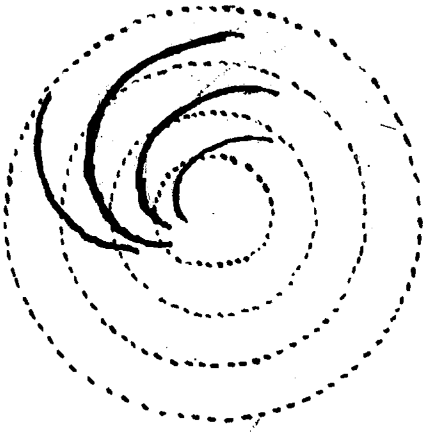


Fig. 77.
Tracings on the head of the right femur in the movement of extension obtained by a steel projection from the acetabulum at right angles to the axis of curvature. The antero-inferior ends of the tracings show a sudden increase of curvature coincident with and representing the external rotation of the femur (MEYER'S retation) at the close of extension. Omitting this local increase the other parts of the curves form the thread of a right winding screw.

minimum: and between the completion of these movements there will be a succession of extents of congruence which will be

1. It is shown by actual experiment that it is impossible to consider a pure rotation as the sole movement of the head: for then the paths of movement would have been concentric circles round the polar extremity of the main axis.

determined by the successive adaptations of the opposing surfaces in both longitudinal and transverse curvatures. The geometric equiangular spiral is the curve which fulfills the condition of successive adaptations of the opposing surfaces, that is a curve the angles of whose cordinates are equal at any distance from its apex and whose parts subtended by the same polar angle, however different their lengths, are geometrically similar but greater or smaller as the curve advances away from or towards the apex. The opposing surfaces thus generated would be the convex and concave elements of a conical screw combination.

The elements of such, if both are constructed of even comparatively unyielding materials, do not coincide, and consequently do not afford any servicible result, till they have been screwed home: but when screwed home the elements are coincident and fixed. In screwing and unscrewing such a combination there is one general direction by which the movements must be guided,- a rotation of one or the other, or of both in opposite directions, in the axis of the combination: the primary movement is movement along the thread of an equiangular screw and the secondary movement is across the thread and will be on a path of similar characteristics. In virtue of the combination of these movements a point on the superior surface of the head passes upwards, forwards, and inwards, so that there is an advancement of the whole head within the acetabulum in the movement of extension. Lastly, in order to maintain the succession of surface adaptations, so that there will be no sudden loss of stability in unscrewing the combination, the axes of the elements must from their coincidence in the locked position diverge from one another, and this occurs in the secondary rotatory movements of the femur.

The movements within the hip joint are not, therefore, movements of revolution, but in passing from a position of semi-flexion to one of full extension the movement of the head of the femur is one of rotatory gliding over the opposite area of the acetabulum. This movement is continued till the opposing surfaces concerned in the weight transmission have become completely congruent: that is the postero-superior area of the head of the femur is screwed on to and fits exactly the iliac and the superior ischial areas of the acetabulum To reach this position the axis of movement gone through by the head of the femur has been one with a direction inwards, forwards, and upwards, the whole head having advanced along this axis so that the intertrochanteric measurement is , on an average, .8 cms. less in the extended position when compared with that of the position of semi-flexion. The femur is now fully locked home in the full congruity of its surfaces and in the tightening of its checking mechanism, the ilio-femoral ligament: and any attempt at further extension would lead to the activity of two opposing factors.

1. The breaking, in the direction of its

establishment, of the congruity of two opposing surfaces and an attempt to make a smaller female element receive the continued advancement of a larger male element, because of the continued action of the tightening mechanism: and

2. the impossibility of any greater extension of the tightening mechanism, the action of which has reached its maximum in a direction which tends to lock the joint at the moment of full extension, the head of the femur having been forced as far as possible within the grasp of the acetabulum.

Hyper-extension would thus not only cause a rupture of the ilio-femoral ligaments but in addition the head of the femur would have to screw itself out of the joint, the thread of which screw would be in an opposite direction to that by which it was locked home.

The same type of mechanism occurs in the action of the anterior articular couple: so that

THE MECHANISM OF THE HIP JOINT IN THE FULL RANGE OF ITS MOVEMENT IS IN THE ALTERNATE ACTION OF TWO CONICAL SCREW COMBINATIONS: BUT IN THE ORDINARY MOVEMENTS AS FAR AS SEMI-FLEXION THE POSTERIOR COUPLE ALONE IS IN FUNCTION, BEING CONCERNED IN THE WEIGHT TRANSMISSION OF THE BODY.

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